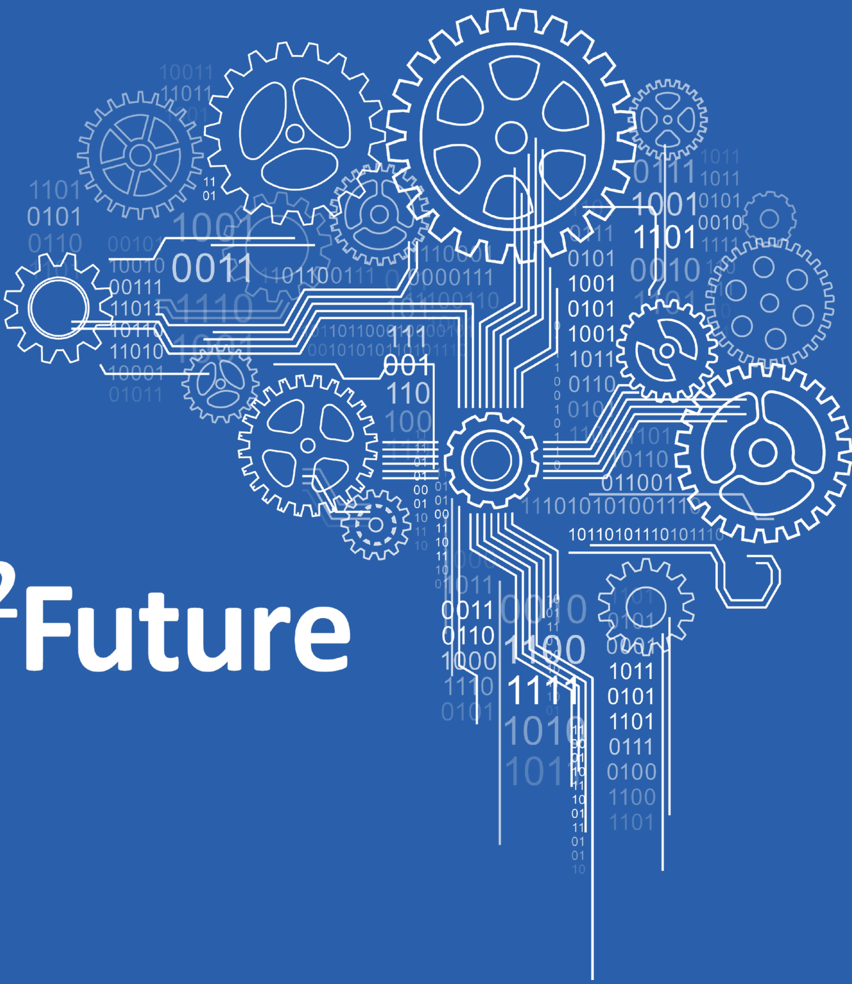
Pro^{2}Future



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Introduction

One of the most profound socio-technical phenomena of the last decade is the increasing blurring of boundaries between the digital and the physical world, dramatically impacting product creation and manufacturing industries. Digitalisation, and consequently virtualisation have opened an unexpectedly wide spectrum for possible future scenarios of how we think about future products (smart/ digital/ online products), and their production processes and systems (smart factories, digital production, online manufacturing) together with new services. **Pro²Future** aims to be the first Centre of Excellence worldwide, addressing this entanglement in research, development, deployment and industrial practice.

Pro2Future (**Pro**ducts and **Pro**duction Systems of the **Future**) is an Austrian Research and **Competence Centre for Excellent Technologies** funded by the **Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology**, the **Federal Ministry for Digital and Economic Affairs**, and Austria's **strongest provinces** in **industrial leadership**, the **Provinces** of **Upper Austria** and **Styria**, within the **COMET K1 4th Call** funding scheme under **contract FFG** 854184. The legal entity of **Pro²Future** has been founded on March 27, 2017 (Landesgericht Linz FN 469403z, April 20, 2017), and the **corporation Pro2Future GmbH**, owned by Johannes **Kepler University Linz (JKU)** (20%), **Graz University of Technology (TU Graz)** (20%) **FRONIUS International GmbH** (20%), **AVL List GmbH** (20%) and **Upper Austrian Research GmbH** (20%) is in operation since **April 1, 2017**. **Pro²Future** operates a **headquarter** at **JKU** in **Linz**, and **subsidiaries** in **Graz** and **Steyr**.

Pro²Future attempts for next generation products and machines equipped with **cognitive capabilities** as to **perceive**, **understand**, **interpret**, **learn**, **reason** and **deduce**. Cognitive systems exceed established smart or intelligent systems by evolving from (i) **sensing to perceiving** - interpretation of semantic background of gathered sensor data, (ii) **analysing to understanding** - identification of causal connections between semantic data representations to create a fundamental, context-based understanding of input data, (iii) **relating to reasoning** - evaluation of critical aspects for decision making, and (iv) **adapting to learning** - evolution from pre-programmed system behaviour to automatic adaption of behaviour models according to changing environmental contexts. In popular science terms, cognitive products could be referred to as "**products that think**" and "**production systems that think**".

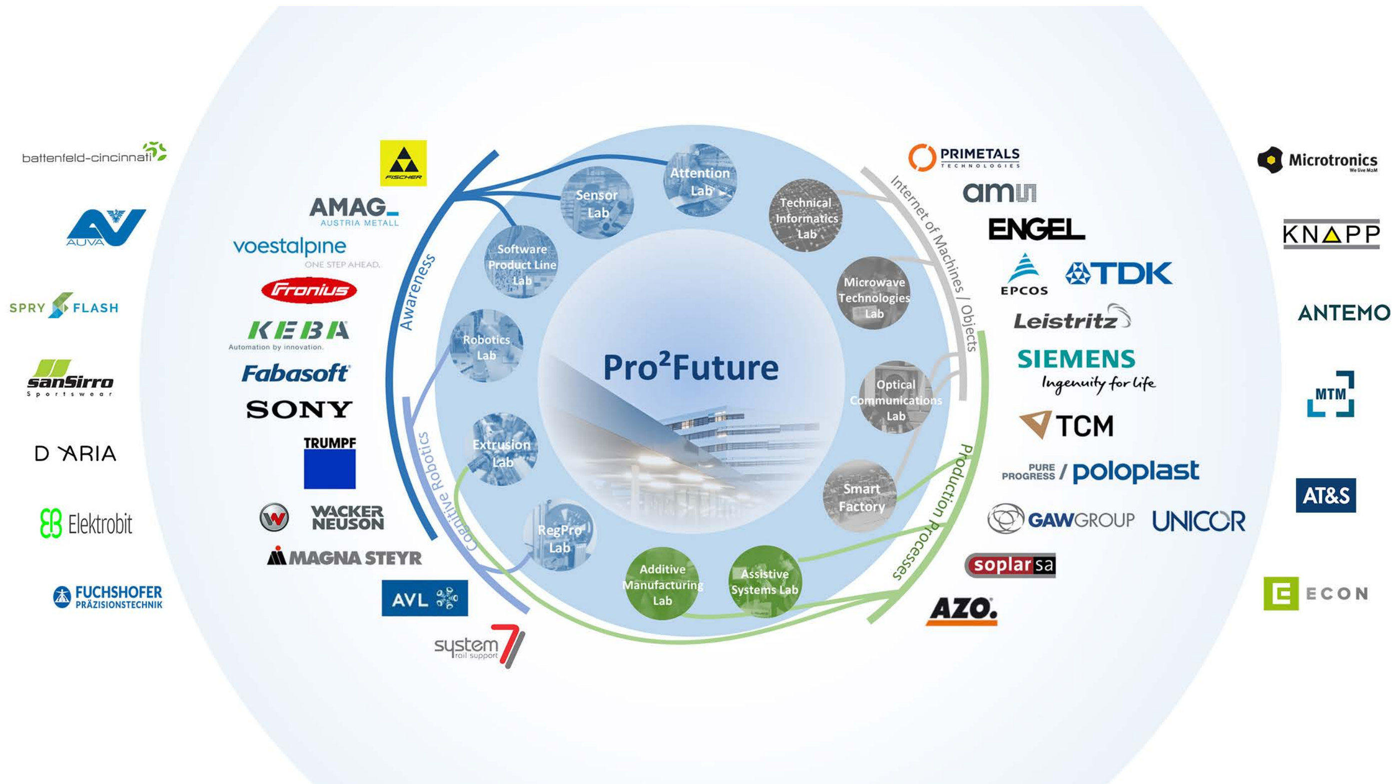
Pro²Future develops **Cognitive Industrial Systems (CIS)** by **embedding cognitive capabilities** into **products** and **manufacturing systems** so as to enable them to **perceive**, **understand**, **comprehend**, **interpret**, **learn**, **reason** and **deduce**, and **act** in an **autonomous**, **self-organized** way - together **with humans**. Pro²Future seeks the consolidation of the Centre's research results in **two core areas**, namely **(i) Cognitive Products (Area 4.1)**, and **(ii) Cognitive Production Systems (Area 4.2)**. In order for this, Pro²Future involves **goal-oriented research** to underpin **product** and **manufacturing innovations** based on **empirically evidenced** applied research results. This is coming from three **underpinning areas**: **(i) Perception and Aware Systems (Area 1)**, **(ii) Cognitive Robotics and Shop Floors (Area 2)**, and **(iii) Cognitive Decision Making (Area 3)**. These five thematic fields are the basis of the **research** and **organisational structure** of **Pro²Future**.

Pro²Future is a joint effort of (i) Austria's **top-level industries**. The consortium of **company partners** in the first funding period (2017-2021) have been **world leading Austrian industrials** in the domain **process industry** (steel: **AMAG**, **Primetals Technologies**, **voestalpine Stahl**, polymers: **Azo**, **GAW Group**, **Leistritz Group**, **Poloplast**, **UNICOR**), software, automation and control (**AVL List**, **Fabasoft**, **KEBA**, **Siemens**, **System7**), equipment and components (**EPCOS**, **Magna**, **SONY Europe**, **Trumpf**, **Wacker Neuson**), and end-products (**Fischer Sports**, **Fronius**) for cooperative research and innovation. For the upcoming funding period (2021 – 2025) consortium of **company partners** has significantly expanded. Among the **new company partners** are **Antemo**, **AT & S**, **AUVA**, **Elektrobit**, **battenfeld-cincinnati**, **D-ARIA**, **D-MTM**, **Fuchshofer**, **sanSirro**, **Spryflash**.

On the **scientific partner** side, Pro²Future is underpinned by the nations **top academic institutions** in **Technology and Engineering** in Upper Austria (**JKU, Johannes Kepler University Linz**, Faculty of Engineering and Natural Sciences) and Styria (TU Graz University of Technology, Faculty of Electrical Engineering and Information Technology, Faculty of Computer Science and Biomedical Engineering, Faculty of Mechanical Engineering and Economic Sciences), and alliance with the **most distinguished European and international universities** in the field of cognitive industrial production systems (ETH Zürich, EPFL Lausanne, TU München, DFKI Kaiserslautern, KIT Karlsruhe, DFKI Saarbrücken, University of Stuttgart, University of Passau, Nanyang Technological University Singapore, Osaka University).

Naturally, the activities of Pro²Future are embedded into the EU Research Agenda, especially the H2020 program in the pillars Excellence in Science (ERC, FET), Industrial Leadership (LEIT) and Societal Challenges regarding energy, transport and materials, and aligned with the upcoming Horizon Europe funding framework.

Pro²Future is endorsed by the Provinces of Upper Austria and Styria, Austria's strongest provinces in industrial leadership, with a R&D quota of 3.19% (Upper Austria, 2019) and 4.91 % (Styria, 2019), compared to the average of 3.2 % of GDP (Austria, 2019). The creation of a COMET K1 Centre along this geographical and industrial axis will enhance and enrich the map of Austrian research institutes in a significant manner, scientifically as well as from a competence viewpoint, and sustainably boost the innovational strength of these industrial regions.



2

Pro²Future: A COMET K1 Centre

Since the late 1990's research and innovation support programmes began to go beyond the provision of funding for research and innovation via institutional funding or single, rather narrowly defined research and innovation projects and instead, increasingly more innovation system oriented approaches were deployed. Competence Centres Programmes present such approaches.

By definition, Competence Centres (CCs) are structured, long-term, research and innovation collaborations in strategically important areas between academia and industry/public sector. They focus on strategic research agendas, support strong interaction between science and industry, providing truly collaborative research with a medium to long-term perspective.

Competence Centre Programmes (CCPs) are usually major initiatives within their national innovation systems. Several innovation agencies have launched this type of programme to support CCs with public funding.

Core activities of Competence Centre Programmes at the centre level are the development and operation of research programmes in strategic and multi-firm projects. Competence Centres perform distinguishable activities separate from the operation of the R&D programme and focus on: (i) **Exploitation of research results** by means of IPR and spin-offs, (ii) **Training of PhDs and master students**, (iii) **Dissemination of research results** via publications, conferences etc., (iv) **Stimulation of networking and knowledge transfer**, (v) **Acquisition of third-party funding** (incl. EU sources), (vi) Provision of research infrastructures, and **(vii) Provision of market intelligence**.

In Austria, the "COMET Centre" is one of the lines of the Austrian programme COMET, the "Competence Centres for Excellent Technologies". The programme is a funding scheme of the Austrian Research Promotion Agency FFG, already launched in 2006, to develop new expertise and encourage greater internationalisation as a sign of excellent cooperative research.

The COMET objectives are:

(i) **Developing and focussing competences** through long-term research cooperation between science and industry at the highest level;

(ii) **Strengthening Austria as a business location**: accelerating technology transfer to industry should serve to create new products, processes and services, open up new markets and increase the innovative capacity of companies;

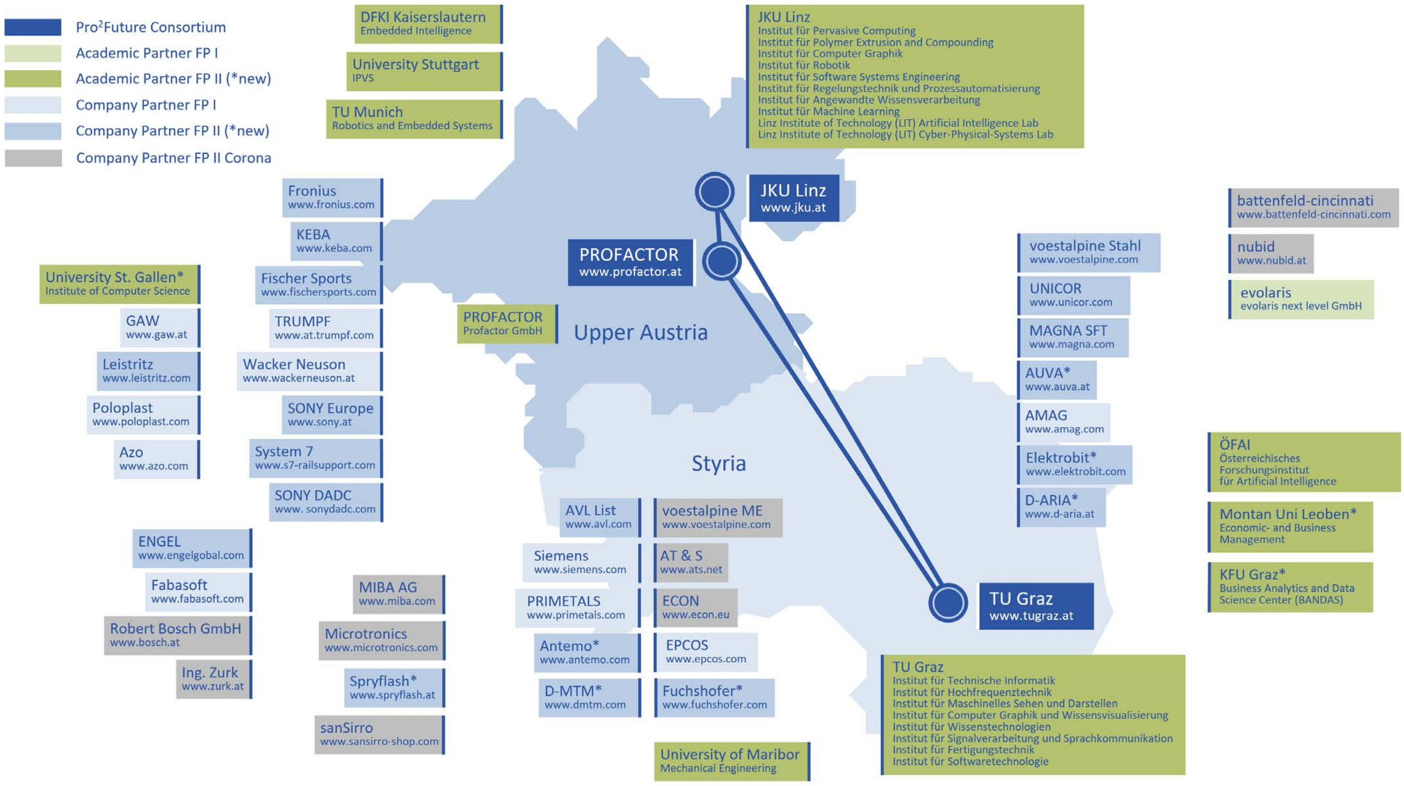
(iii) **Strengthening Austria as a research location**: excellent cooperative research should trigger new research impulses and establish promising/emerging fields of research;

(iv) **Strengthening the competitiveness of science and industry** by driving internationalisation as a sign of high quality cooperative research: involving internationally-renowned scientists, organisations and companies, positioning COMET Centres as internationally attractive partners, and ongoing benchmarking with top research institutions are designed to generate an edge in international competition.

(v) **Establishing and developing human resources**: increasingly attracting scientists of international renown, creating structured career models for scientists, and actively supporting intersectoral mobility for research personnel in order to intensify the transfer of know-how.

The achievement of the COMET objectives and its impact are assessed by quantitative and qualitative indicators at project and programme level. The indicators and **target values** are directly derived from the programme objectives and include among others (i) the **number of publication**s, IPRs, etc., (ii) the **share of strategic research** in overall research programme, (iii) the number of **international partners**, (iv) the **participation in international R&D projects** (e.g. EU projects), and (v) the acquisition of additional external funds from contracts with companies.

COMET K1 Centres aim to develop and focus competences COMET K1 Centres aim to develop and focus competences through excellent cooperative research with a medium to long-term perspective. They conduct research at top international level and stimulate new research ideas in their fields. Continuous international benchmarking must be ensured. They contribute to initiating product, process and service innovations with a view to future relevant markets. K1 Centres define multi-year research programmes aligned to the strategic interests of science and industry. They include at least five company partners and consolidate their competences by establishing relevant human resources being further developed via structured career models. Their general duration is 8 years (stop-or-go evaluation after 4 years), the public funding ranges from 40 to 55 %, and the Federal funding is limited to max. EUR 1.7 million per year.

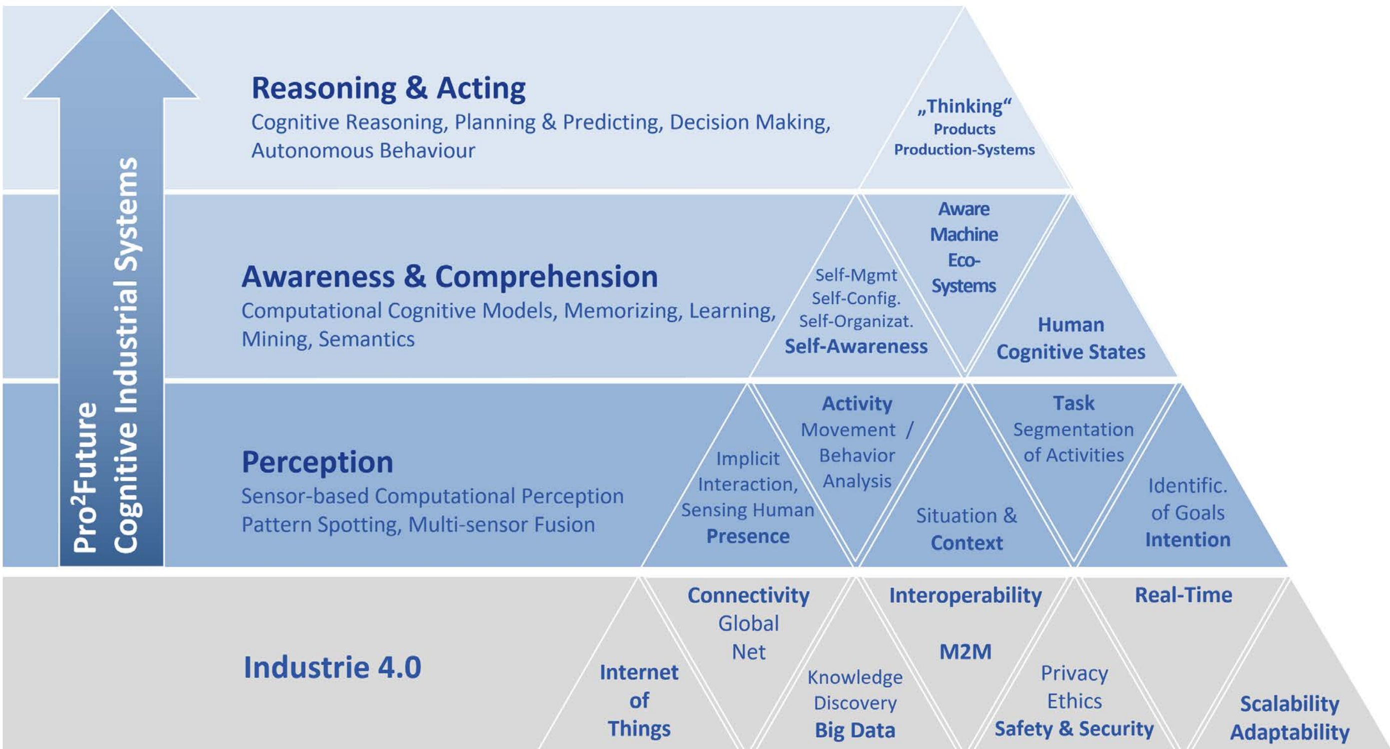


Pro²Future and a second COMET K1 competence centre, the Centre for Digital Production (**CDP**), have to jointly developed a **Common Research Programme (CRP)** -based on the respective complementary competencies- in the form of **demonstrator projects**. **24 (Pro²Future)** and **27 (CDP) researchers** have worked on CRP, successfully delivering **proofs of concepts** for **new solutions** to **technologically significant** and **industrially relevant** problems, in **3 demonstrator projects** exhibiting **12 demo cases**.

3

Vision and Objectives of Pro²Future

Pro²Future has been founded at times (2017) when the blurring of boundaries between the **digital** and the **physical world** started to dramatically impact **product creation** and **manufacturing industries**. At these very first steps towards a radical **"Digitalisation of Industries"** a wide spectrum for possible future scenarios of how we think about **future products** (smart products, digital products, online products), and the processes and **production systems that create them** (smart factories, digital production, online manufacturing) together with new services and business models emerged. Key to our thinking was a **Product-Production Systems Co-Design**, **Co-Creation**, **Co-Operation** and **Co-Existence** of **products** and **production**. The overall vision of **Pro²Future** thus was to attempt to be the first center of excellence worldwide, addressing the **entanglement of products and production systems of the future**, in **research**, **development**, **deployment** and **industrial** best **practice**.



Pro²Future research goals fostering Cognitive Industrial Systems towards next level ICT in industries.

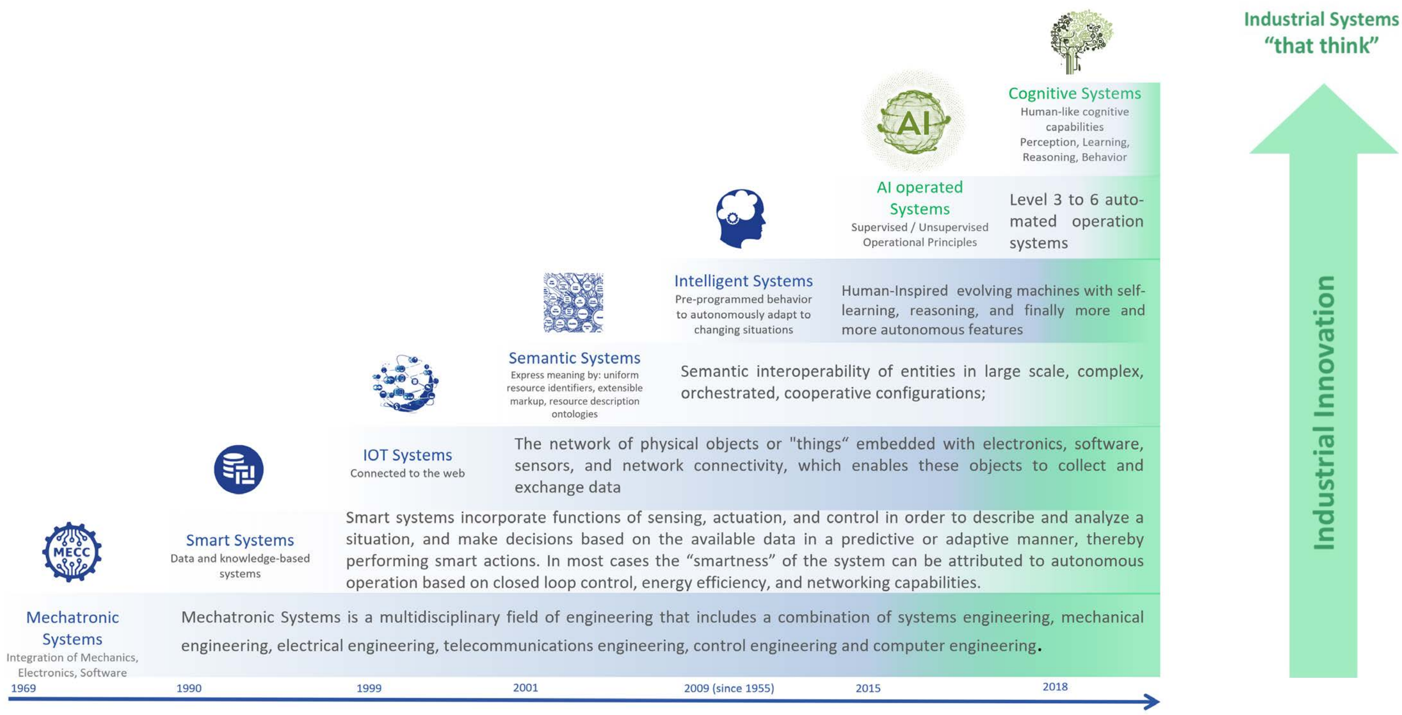
In research, the **Pro²Future** initiative builds on top of the consortiums expertise in mechatronic systems, networked embedded systems, engineering of distributed software, cyber-physical systems, smart/pervasive/ubiquitous systems, systems of systems, big data analytics and data-driven predictive models, semantic and intelligent systems, and the exploration of innovative ICT that intended to go far beyond the then popular science approaches (like Industrie 4.0, Industrial Internet of Things, Web of Services and Physical Internet, etc.), namely to the next level of ICT in industries referred to as **Cognitive Industrial Systems**.

Pro²Future attempts for next generation **products** and **manufacturing machinery** (holistically combining batch and continuous process industries), with **embedded cognitive capabilities** so as to **perceive**, **comprehend/understand**, **interpret**, **learn**, **reason** and **deduce**, and act in an **autonomous**, self-organized way together with humans, i.e., **human consumers** and **human (industrial) workers**. Expressed in popular science terms, the **Pro²Future** research aims for ***"products that think"*** and ***"production systems that think"***. In the upcoming funding period (2021-2025), **Pro²Future** will attempt to rigorously work on the embedding of **AI** (Artificial Intelligence) **technology** into **products** of the future, and the **symbiosis** of **Human Intelligence** and **AI** in **production systems** of the future.

*The **overall goal** of the K1-Center Pro2Future is to carry out **Cognitive Systems Research** and **integrate** the **achievements** into the **Industrial Lifecycle** of **Products** and **Production**. **Building on** and **exploiting existing research** areas and expertise from the last six decades of technological evolution (Figure 1.1 2), the K1-Center has successfully created and will continue to deliver **Cognitive Industrial Systems**, **as a joint undertaking** between **Austria's top-level industries** (formed around **process industry**, **software**, **automation and control**, **equipment and components**, and **end-products**) together with the nation's **top academic institutions in Technology and Engineering** in Upper Austria (**JKU, Johannes Kepler University Linz**, Faculty of Engineering and Natural Sciences) and Styria (Graz University of Technology, Faculty of Electrical Engineering and Information Technology, Faculty of Computer Science and Biomedical Engineering, Faculty of Mechanical Engineering and Economic Sciences).*

The **long-term vision** of the **Pro2Future initiative** addresses cognitive products and production systems in an overarching and interleaved way.

The **research visions** are structured along the following lines of the evolution of ICT in industrial research and innovation:



Vision and Objectives of Pro²Future

- **Mechatronic Systems** – a symbiosis of mechanics, electronics and software, originating at the conjunction of **MECHAnical** and **elecTRONICal** engineering by the Japanese engineer Tetsuro Mori in 1969, that was later extended to computer, telecommunications and systems engineering representing the backbone of ICS, providing shop floors, robotics, tools and machines in an industrial context.

- **Smart Systems** – represent data and knowledge-based technologies. The focus lies on the acquisition, storage and retrieval of knowledge and data. It provides the means to perform decision-making based on facts, trends or historical data. The respective technologies serve as the **perception system** and contribute to the **reasoning system** of an ICS.

- **IoT Systems** – build upon the connectedness of devices to the internet or other devices within a network. This connectedness is exploited as a transportation network to gather information from or send commands to devices. This represents the **nervous system** of an ICS.

- **Semantic Systems** – explore how to express meaning or information in a standardized way which can be used e.g. for machine-to-machine communications. The respective technologies serve as the **"language system"** of an ICS.

- **Intelligent Systems** – investigate how to use pre-programmed human-like behavior to adapt to changing environments (self-organization, adaptation and cooperation of systems). The respective technologies provide the **learning**, **planning** and **reasoning** component of an ICS.

- **AI operated Systems** – very recent (since around 2020) advances of AI based methods for controlling the behavior of systems have impacted the research goals of Pro²Future at its transition into the upcoming funding. ICS are concerned more and more with situations where **human intelligence** comes across **AI controlled/ operated machinery** or **product functionality**. This poses a grand challenge to the future of AI in general and has been adopted as a top priority research agenda for Pro²Future in FP2.

- **Cognitive Systems** – require **innovation breakthroughs** at every layer of information technology, starting with **computing systems design**, **information management**, **programming**, and **machine learning**, and, finally, the **interfaces between machines and humans**. **Cognitive Products and Cognitive Production Systems** will have to adopt human-like capabilities like perception, learning, reasoning, planning and behavioral control, or in short, will have to be able to **"think"**, **understand** contextual information, and to provide a **seamless interfaces** to the user to **adapt**, **act** and **react** in **real-time** to spontaneous **information**, **goals** and **tasks**. They **exceed on AI operated systems** by **evolving** (i) from **sensing to perceiving** – interpretation of semantic background of gathered sensor data, (ii) from **analyzing to understanding** - identification of causal connections between semantic data representations to create a fundamental, context-based understanding of input data, (iii) from **relating to reasoning** - evaluation of critical aspects for decision making, and (iv) from **adapting to learning** - evolution from pre-programmed system behaviour to automatic adaption of behaviour models according to changing environmental contexts.

In order to develop such **Cognitive Industrial Systems (CIS)**, the research program of Pro²Future seeks the consolidation of the Centre's research results in **two core areas**, namely **(i) Cognitive Products** (Area 4.1), and **(ii) Cognitive Production Systems** (Area 4.2). So **Products** and **Production** are the very essential concerns of the centre. In order for this, **Pro²Future** involves **goal-oriented research** to underpin product and production innovations based on empirically evidenced applied research results. Support is thus coming from three **underpinning areas**: **(i) Perception and Aware Systems**, **(ii) Cognitive Robotics and Shop Floors**, and **(iii) Cognitive Decision Making**. These five thematic fields are the basis of the **research** and **organisational structure** of **Pro²Future** (see chapter 4).

Pro²Future focuses its research on the topics (i) **system and software architectures** for cognitive industrial systems, (ii) **methods and approaches** for ICT-supported system-/automation-/perception-/ control engineering, (iii) **control of complex material-/production-/ product-/process chains**, (iv) **construction methods** for cognitive industrial systems, (v) **engineering of complex industrial systems**, (vi) **engineering of autonomous industrial systems**, and (vii) **engineering of heterogeneous industrial systems**.

The type and nature of research work in these **five areas** yields \`technology concepts formulated´ (TRL 2), \`experimental proofs of concept´ (TRL 3), and \`technology validated in lab´ (TRL 4), and are conducted in multifirm-projects (**MFPs**) and strategic projects (**SPs**) within the **COMET funding scheme**. Activities aiming at technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies) (TRL 5), technology demonstrated in relevant environment (TRL 6), and system prototype demonstrations in operational environments (TRL 7) are performed in the **non-COMET scheme**. **Basic research** creating the foundational grounds of the goal oriented research in the core areas of Pro²Future is provided by the **academic partners** of Pro²Future in their own domain, and **outside the COMET funding scheme** (see also chapter 4).

4

THE AREA STRUCTURE

A Joint Effort Towards Products and Production Systems of the Future

Pro²Future's Research Program is consolidating research results within two **core areas**, i.e. AREA 4.1 Cognitive Products and AREA 4.2 Cognitive Production Systems, **underpinned** with three major **scientific areas**, each taken from foundational and goal-oriented research disciplines related to cognitive systems, namely AREA 1 Perception and Aware Systems, AREA 2 Cognitive Robotics and Shop Floors and AREA 3 Cognitive Decision Making.

Visualisation of the overall research program of the Pro²Future initiative. Research efforts are structured into four main areas, whereby Areas 1 to 3 encompass foundational and goal-driven research. The accomplishments from these areas are transferred to Area 4, where exploitation and creation of cognitive industrial products and production systems take place.

In **Area 1 "Perception and Aware Systems"**, researchers focus on **simplification of interactions between humans and machines** in order to facilitate the implementation of **sophisticated cooperation and reasoning systems**. Beginning with mechatronics systems and spanning up to "Internet of Things"- and intelligent systems, Area 1 investigates and creates cognitive systems that are able to sense, reason, interact and cooperate to optimally solve problems and adapt themselves to changing contexts.

Area 1 works towards (i) **Human Aware Machines** (sensing, interpretation and understanding context-, activity-, attention-awareness), (ii) **Assistive Machines** (cognition-based assistance services for cognitive and decision making processes), (iii) **Self-aware Machines** (modeling self-description and self-management of production machines), and (iv) **Cooperative Machine Ensembles** (creation of stand-alone eco-systems of production machines, coordination in production ensembles).

Its projects aim specifically towards increasing **machine-machine cooperation** and the timely **adaptation of machines to human needs** and actions. Area 1 specifically contributes to Area 4.1 in terms of **integration of cognitive functionalities** into end-consumer products as well as to Area 4.2 regarding interaction processes enabling the realization of cognitive production systems.

Area 2 "Cognitive Robotics and Shop Floors" is directed at research on robotic systems and production systems to be incorporated into a fabric of cyber-physical industrial systems to drive the ongoing modernization of industry. Focus is set on the **reinvention of adaptable mechatronic and robotic production systems** and consequently the **adaptability of entire production processes** in shop floors by means of embodiment and respectively connecting physical entities with virtual representations.

Area 2 works on (i) **Reasoning and Acting** (developing systems to manipulate and monitor industrial information and workflows and logistics), (ii) **Production Process Management** (interconnecting inventory management with shop floor logistics, QM-systems and serialization), (iii) **Multimodal Knowledge Transfer and Learning Support** (supporting tools that allow understanding human activities with respect to workflows and actions on the shop floor), and (iv) **Cognitive Shop Floors** (eco-systems of cognitive power tool entities, equipped with higher organizational abstraction layers for representation of complex production procedures, awareness and prosecution of general superior goals).

Area 2 mainly contributes to the realization of Cognitive Production Systems in Area 4.2, **integrating cognitive functions** like perception, self-awareness, user modeling and interaction modalities from Area 1 and **decision-making processes** from Area 3 **into automated production processes**. Furthermore, experience in the development of cognitive tools in the industrial field of application contributes to the **realization of cognitive end-user products** in Area 4.1.

Area 3 "Cognitive Decision Making" focuses on researching the aspect of **computational decision-making**, starting with the creation of **novel analysis techniques for large amounts of data**, via the development of **classification systems for industry**, reaching up to the development of industrial systems that **autonomously forecast** undesirable system states and **pre-emptively** take unobtrusive, **corrective action** on all granular system levels from single production actuator to ensembles or even control of complete shop floor entities.

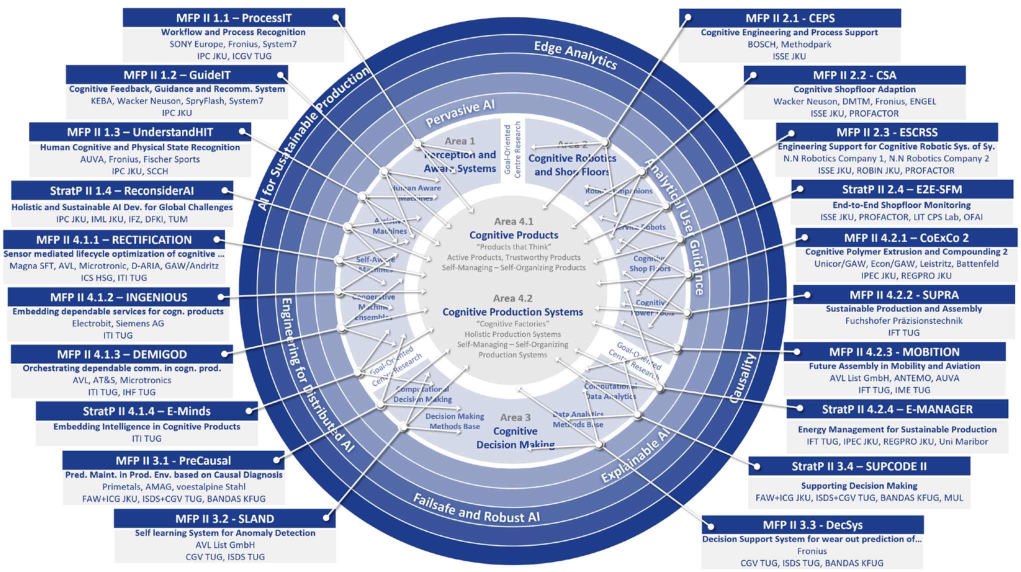
Area 3 works on (i) **Data Analytics Method Bases** (general cognitive functions for base and reality mining, scientific, semantic visualization of data), (ii) **Computational Data Analytics** (providing cognition-based functions for handling of data under uncertainty), (iii) **Decision Making Method Bases** (models of cognitive functions for decision making including goal and plan representation, resource allocation and optimization of processes), and (iv) **Computational Decision Making** (transparent automatic multi-criteria, multi-resource decision making, choice modeling and heuristics).

Area 3 contributes the **identification of transparent and optimal solutions** under time, resource and strategy constraints, and processing of reliable as well as potentially unreliable data. These contributions represent fundamental components of any autonomous, cognitive production system or end-user product equipped with perception and self-awareness.

The results of Areas 1-3 enable the direct fusion of the respective contributions (perception, context interpretation, awareness, decision-making, learning, and executive behaviour) into cognitive systems headed by Area 4, with the subcategories of 4.1 Cognitive Products and 4.2 Cognitive Production Systems.

The focus of **Area 4.1 "Cognitive Products"** lies in the development of: (i) **Self-organizing Products** - products that manage their processes without need for interaction with centralized control units and are able to react to disturbances that limit their operability in a corrective manner), and (ii) **Active and Trustworthy Products** - products that communicate actively with other products and production lines to increase productivity by decreasing overheads. A trust system manages resource allocation to solve scheduling issues.

A separate yet related subject matter is investigated in **Area 4.2 "Cognitive Production Systems"**, focusing on: (i) **Cognitive Factories and Factory Floors** - by processing data generated by their individual subsystems and components, cognitive factories react under real-time constraints to situations occurring in industrial systems, both properly as defined in the production flow and unexpectedly and potentially impeding to productivity; (ii) **Holistic Production Systems** - design and development of entire industrial shop floors starting at each individual component and their interactions to subsystems. In this manner, decentralized systems can be conceived that can enact arbitrarily complex changes to the production chain. (iii) **Self-organizing Production Systems** - in effect entire industrial installations that communicate and cooperate to optimize productivity. Each of the components of such an installation generates shares and processes information in order to pre-emptively detect unexpected system states and take preventive measures.



Scientific advance, technological progress and changing industrial needs have led to enhance the research agenda of Pro2Future with **cross-area topics**. Among those are **Artificial Intelligence**, **Complexity Science** and **Safety** related **Amendment Topics (PervasiveAI, Engineering for Distributed AI, ExplainableAI, Analytical User Guidance, Causality, Edge Analytics, Failsafe and Robust AI, AI for Sustainable Production.** So while Pro2Future **will continue** to **deepen** the **thematic focus** along the research goals **in the Areas 1, 2, 3, 4.1 and 4.2.**, cross area research will be addressing the dynamics of industrial digital transformation.

EXECUTIVE SUMMARY

Area 1

Perception and Aware Systems

Area Leader: Prof. Alois Ferscha (JKU)
Area Manager: DI Michael Haslgrübler (Pro2Future)

Goals

The Perception and Aware Systems Area is devoted to apply state of the art research drawn from **cognition, perception**, **cognitive interfaces**, **interaction,** and **cooperation** to an industrial context. Thus, area 1 focusses on scenarios where machines (i) should **adapt to workers' limitations (Human Aware Machines),** (ii) support workers in their **strengths** (**Assistive Machines**), and (iii) **cooperate** with other **ICT systems**, thereby forming **collaborative industrial ensembles**, in order to achieve (i) and (ii).

For **Machines Cooperating with Machines,** we enabled true **autonomous collaboration** from **single machines** to complete **ensembles** based on (i) **self-awareness** and **self-organization** of individual entities (hard and software) and (ii) **goal-oriented entanglement of actors**, while still maintaining **traceability** and **transparency** of ongoing communication and **decision making** in these full-**automated processes** by providing **identification** and **communication** of the most important, critical, and decisive factors and meta data.

For **Machines Adapting to Humans,** we provide **safe** and **supportive interaction** between systems and human workers based on a fundamental **awareness** of **presence**, but enriched through understanding of **current context**, **ongoing activities** as well as an assessment of **higher-level cognitive states** of the human co-workers. This especially includes assessment of **orientation** and **intensity** of **attention** of the humans, estimation of **cognitive load** levels, as well as evaluation of **operator skill** levels to enable the selection and execution of appropriate supportive measures. These ambitions required us to develop a tight and encompassing **feedback loop between human behaviour** and system **reactions**, resembling human **perception and interpretation capabilities** of observed behaviour, often in the form of **nonverbal** and **implicit interaction patterns triggered by the system** steering human operators away from sub-optimal outcomes of their behaviour.

Approach

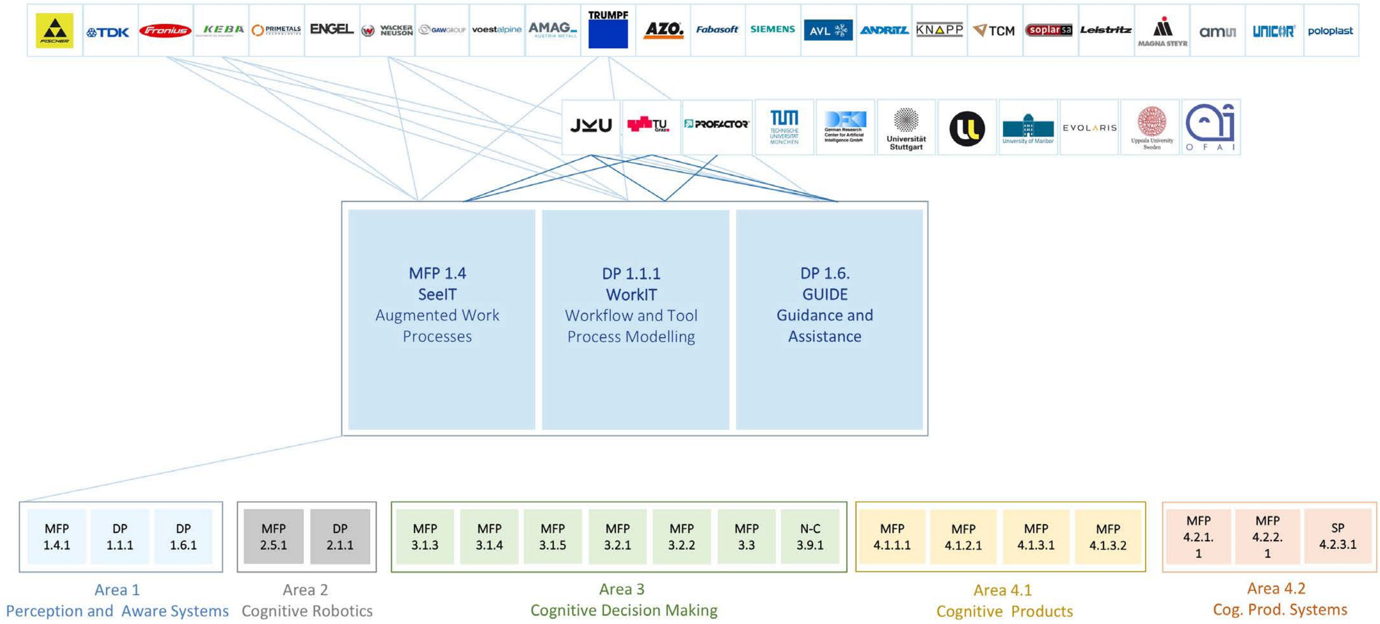
Area 1 mainly relies on **established methods** and **technologies** for the computational **recognition** of **context** and **modelling** of **self-awareness in embedded distributed systems** and **interaction design.** These methods are extended in three areas of our work: sensing, reasoning, and actuating and applied to solve needs of industrial partners and advance scientific understanding in these areas

Sensing – With tight cooperation with our lead contributors (JKU), who has a **long lasting experience** in this field, we implemented several sensing components and also fused heterogeneous sensor sources together in order to be able to perceive, abstract, interact, cooperate and learn of all the types of context and activities as well as **higher level cognitive derivatives.** We used (i) **visual sensors** (cameras for visual analysis, motion capturing) (ii) **infrared** (depth sensing, eye tracking) (iii) **auditory** (binaural micros) (iv) **tactile** (button, pressure sensors) (v) **motion** (Shimmer IMUs, Phidgets) for e.g. (I) **behaviour analysis** (activity tracking sensors) (II) **estimation of visual attention** (wearable eye gaze tracker) and (III) **measuring somatic indicators** of **attention** (skin conductance (GSR), pupil dilation, heart rate variability).

Reasoning – We implemented two lines of work, **reasoning about** the **worker** or the **environment**. For the first part we used **modelling techniques of human behaviour**. E.g. for Cognitive load detection we employed high-level cognitive models (e.g. SEEV attention model), by making use of **physiological indicators** such as heart rate and breathing, body posture and movements. We also investigated how behavioural data reveals operator skill levels, e.g. by interaction patterns with user interfaces or by the data captured by motion sensors during use.

For the second part, the reasoning about the environment we built e.g. a **Location awareness** – component by making use of **embedded computer vision** and **sensor fusion** techniques, combining multiple imaging modalities, such as RGB, depth and infrared but also inertial measurements to perform **simultaneous localization and mapping** to have **3D models** of the environments, which we use to annotate semantically and can be used to provide location specific information to users.

Actuating Having established computational awareness, of operators and users, based on sensing and reasoning, we used **neuro-physiological models**, e.g. Multiple Resource Theory, to create a new forms of interaction designs. We built hardware and software prototypes, e.g. in the form of wearables, which are able to **stimulate human operators subliminal** but effectively, providing a long-overdue change from today's attention-grabbing towards attentive-preserving computing devices. In addition, these devices are not only **designed to fit into processes** of their use, freeing users from adapting to the device, but are **adapting to operators** by assessing e.g. their skill level or the current cognitive load and **provide help if human need requires it,** e.g.



by providing explicit help, e.g. in the form of video snippets or limiting options on user interfaces to a necessary minimum, respectively.

Expected and achieved Results

We expected with our work to move beyond State of the Art **in Human-Aware, Assistive Machines** and **Cognitive Modelling**. A significant step beyond current state-of-the-art was made in the field of s**elf-aware, human aware and assistive, cooperative machines** by development of encompassing **perception**, **interpretation** and **understanding** of **human activities** and underlying **motivations** to enable true **collaborative cooperation** between human and machines in the industrial production process of several of our company partners. The **interpretation** of **cognitive states** of human workers requires the application and realization of complex computational models of (i) **perception**, (ii) **attention**, (iii) **motivation** and (iv) **executive behaviour** based on models from **cognitive** and **behavioural psychology**.
Based on the aforementioned three pillars of sensing, reasoning and actuating, we realised the following: (i) **Abstractions** and **models** of **industrial worker context** where effort (body pose, gestures, movement, etc.) is of constituent and essential significance; (ii) A **cooperation framework** for cognitive entities, forming a collective of devices to facilitate **user guidance** through complex workflows and assembly situations; (iii) A **recognition architecture** making use of heterogenous sensors for several recognition challenges; (iv) An **end-to-end framework** for capturing low-level visual sensor data and transforming it into high-level actions such as the active step in the manufacturing workflow and a users' **cognitive state** and **skill level**; (v) Providing the fundamental **basis for** future **self-aware system**, by following principles of **autonomous operation**, **self-adaptation,** and **self-improvement;** (iv) a pre-emptive quality assurance system with seamless integration of quality assurance data into existing quality management processes (vii) Provided insights to the scientific community and gathering feedback on our results in **18 peer-reviewed outlets: one Journal Publication and seventeen conference publications**

The aforementioned results were developed in **DP1.1 WorkIT - Workflow and Tool Process Modelling, DP1.6 Guide – Cognitive Assistance** and **MFP 1.4 SEE-IT Augmented Work Processes,** which were started together in January 2018, whereby all three projects are supported by the same Company Partners, namely Fronius, KEBA, Trumpf and Wacker Neuson and are interwoven to avoid duplicated developments and foster synergy effects. These projects are structured along three major axes: "**DP1.1 WorkIT**" deals with the recognition and perception of work situations and workflows (exemplary results: used tool detection from Ego-Centric View; Multi-Sensor Fusion Based Detection of Worker Activities based on IMU and Visual Data), and provide pre-processed sensor data streams to "**DP1.6 Guidance and Assistance"** (exemplary results: A welding helmet with an embedded an eye tracker computing Index of Pupillary Activity; Lightweight prototype for navigation and 3D reconstruction), which creates assistance systems and compute guidance triggers that are further communicated to "**MFP_1.4 SEE-IT**" (exemplary results: Head worn tactile navigation device; Wrist-Worn Embedded Visual/ Tactile Subliminal Stimulation Device), which investigates feedback- and actuator systems to communicate the formulated guidance to the worker. Throughout the funding period we deepened our work from "**DP1.6 Guidance and Assistance**" by adding three more partners, Fischer Sports, Sony Europe and System 7 to the MFP umbrella, with the partners strengthening already existing topics of **skill recognition**, **digitalisation of industrial environments** and **guidance based on unsupervised machine learning**.

Positioning of the Area within the Centre

The challenge for Area 1 is the investigation of **perception and computational awareness** in the domain of cognitive research, which represents a foundational research basis for the efforts of the other work areas. Especially the **focus on** and around system **operators**, is an essential factor in Area 1 and a pillar upon other Areas can build on. We, as well as other researchers, see **perception as a necessary precursor** (i) to give cognitive properties to systems (cognitive products), and (ii) for implementing cognitive systems (cognitive production). It is not enough to, as many companies do, making systems "smarter", but to design and implemented an **aware and human-centric approach** for the next generation of systems, i.e. making computing cognitive.
Our rigorous approach towards cognitive products and production systems is streamlined with activities in the other areas, providing additional value for our and other projects of all areas: E.g. we will integrate **dependable localisation approaches** developed for calculating viewpoint and distance between actuators and workers from Area 4.1; we will employ dependable **wireless communication facilities** from Area 4.1 or use novel production techniques of Area 4.2 for structuring functions of our cognitive headgear; we will use **interoperability techniques** for machine and robot interaction provided by Area 2. With Area 3 we have informal collaboration by exchanging ideas regarding **machine learning** and decision-making techniques.

EXECUTIVE SUMMARY

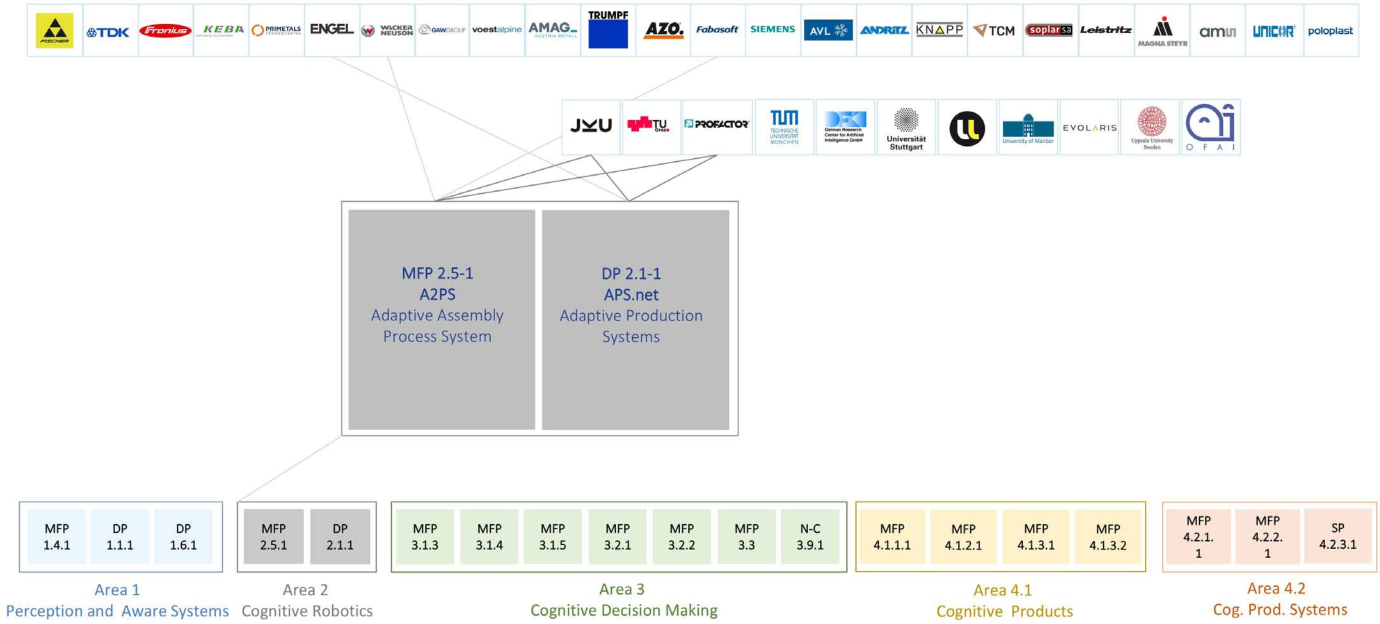
Area 2
Cognitive Robotics and Shop Floors

Area Leaders: Prof. Alexander Egyed (JKU), Dr. Andreas Pichler (PROFACTOR), Prof. Andreas Müller (JKU)
Area Manager: DI Michael Mayrhofer (Pro²Future), formerly Dr. Christoph Mayr-Dorn (JKU), Georg Weichhart (PROFACTOR)

Goals
Changing business environments and the dynamics of modern consumer markets requires flexible production systems capable of adapting to not only short term fluctuations in demand, but also long term flexibility with respect to evolving production systems towards new capabilities in the future.
"Thinking" Shop Floors - In Area 2 the technological basis for cognitive systems, able to adapt production machines (individual systems), entire shop floors (systems of systems), and even the product- and production design and engineering process (design for adaptability) is researched. The main cognitive function addressed is learning, supporting humans with the ability to teach new production processes to flexible machines and shop floors. The ultimate research goal for Area 2 is to enable change and learning at all levels from individual machines to shop floors – naturally supporting humans in contributing/intervening at any one of these levels (cognitive aspects).
"Thinking" Robots - Another major goal of Pro²Future is equipping robots with human-like cognitive functions of (i) **self-awareness** (integration of sensing, perception, interpretation concepts from Area 1), (ii) **autonomous decision making** (integration of computational, multi-criteria decision making processes from Area 2), (iii) capabilities for **handling spatial tasks** (orientation, searching, wayfinding etc.) as well as (iv) **performing** object/workpiece **manipulation tasks** (identification, translation, handling of workpieces) to enable assistive actions (integration of decision making processes from Area 3).
Beyond State of the Art in Cognitive Robotics - Collaborative robotics, including robot-robot and robot-human collaboration, require approaches to create safer and more efficient production processes e.g. improved automatic perception of the human worker and the environment. However, these approaches hardly exceed presence detection for accident evasion. Pro²Future aims at enabling understanding of current human activities and cognitive load. This allows innovative kinds of interaction and learning, to support collaboration between robots/machines and between robots and humans.

To understand adaptation in cognitive robotics and shop floors, Area 2 established the following main goals: (i) realise **learning support for adaptation** (both as a means for better guiding adaptation and teaching new production), (ii) **support the humans** in the loop to set the goals for adaptation, and (iii) **design for adaptability** to support future adaptation goals.

Teaching Manufacturing and Learning How to Adapt is not just about changing the physical structure of a shop floor but it is also about changing its behaviour. This is where most of the "smartness" can be found and hence most of the cognitive aspects of adaptation are to be found in layer 3 as it embodies any form of complex behaviour: from a coordinated manufacturing step that requires synchronous machine behaviour (e.g., a stop action) to continuously changing manufacturing of a product.
Adapting shop floor behaviour is not only challenging but also requires a significant software engineering effort. We thus develop cognitive means for letting humans (e.g., a worker) change this behaviour in an intuitive manner: through teaching and learning, where humans demonstrate and machines repeat. On the most basic level, learning is about remembering past adaptations. If a shop floor existed (in part) then future adaptations may benefit from remembering it. For example, if a set of machines is adapted in a manner that is structurally identical to a previous shop floor adaptation then configuration parameters of these machines may be reusable. And even more significantly, so might be structural and behavioural aspects of their interaction on the shop floor level. Of course, on a more advanced level, "smartness" may also benefit from machine learning and other learning concepts. This should work well for repeatable patterns of interactions that can be demonstrated once and repeated indefinitely. However, it is tricky to understand when a pattern no longer applies (an exceptional situation) or when variations of patterns exist.
Therefore, scenario-driven approaches to teaching and learning are explored also. Moreover, teaching and learning at different levels of granularity: at the level of a machine and its manufacturing step(s) to the level of a shop floor and its structure and behaviour needs during manufacturing.
Human Guided Adaptation is the result of human interaction – from shop floor workers who may trigger adaptation because of a changing production need all the way to production processes where possible goal scenarios are articulated and transcribed by adaptation process engineers. Hence, it must be understood that the adaptation of machines and shop floors could be automated (controlled by a self-optimising software - Area 3) or manual (controlled by workers). However, we always expect a human decision maker to be involved. This human could be a supervisor, a smart contributor, or even a conflict resolver if there are multiple suitable alternatives. It is foreseeable that all four layers in Figure 3.4.1 above impose different challenges onto cognitive guidance. Furthermore, it is clear that humans are a central actor in teaching and learning. They define adaptation goals, they guide/support the adaptation if it is not fully automated (likely the norm), they help decide/resolve adaptation constraints (e.g., you can have A,



you can have B, but you cannot have both - what do you want?), they teach, and they design/engineer. These roles may overlap but are just as likely to involve different kinds of people with different skills and different cognitive needs and abilities.

Designing for adaptability and its evolution is necessary no matter how carefully a machine is designed for adaptation and no matter how many adaptation scenarios a shop floor is able to support. Designing for adaptability and its evolution is about engineering "change" into a machine or even a shop floor that is presently not configurable or teachable. Area 2 explores the continuous evolution of machines and shop floors, and how to better build adaptable machines and shop floors. In doing so, Area 2 also explores how to represent adaptation knowledge in a manner that can be acted upon and reasoned about – for example, by providing a means for defining configuration parameters and dependencies thereof. Here, an important part is to ensure safety and security during manufacturing to prevent harm to humans or machines. This imposes new levels of engineering complexity. Today, it is already hard to ensure the correctness of a single machine or a single shop floor (that is not configurable). In Pro2Future, the goal is to provide adaptation on machines and shop floors levels with a maximum of configurability and it must be assured that each possible adaptation scenario of its machines and the entire shop floor is correct.

Approach

In Area 2, the main goals are to provide the tools, infrastructure and methods to enable adaptive production systems. Production systems in this area consist of human systems and artificial systems that have a certain structure and show a certain behaviour, where the interaction of systems results in complex behaviour visible on a higher level. A shop floor can be adapted through a range of mechanisms: from reconfiguring individual machines to changing machine interaction. We distinguish the following four layers: (i) Adaptive Robotics/ Machines describe configuration parameters that provide means for changing individual machines. These configuration parameters reflect a machine's built-in ability to change as was foreseen by the machine vendors (companies that manufacture machines). (ii) Adaptive Shop Floors describe how machines and other production resources are physically laid out within a shop floor and how this layout can be changed. We speak of the structure of a shop floor – a system of systems – where the structure understands how machines are configured and interact with each other. (iii) Adaptive Production Systems describe how machines interact in context of defined shop floor structure and how this interaction can be changed. We speak of the behaviour of a shop floor that can be changed with or without changing the structure of a shop floor (layer 2) and with or without changing the configuration parameters of its machines (layer 1). (iv) Adaptive Environment (environmental interactions) describes how shop floors and their machines may adapt to changing environment parameters.

Expected and Achieved Results

Area 2 delivered methods and tools to support the design of systems (of systems) capable for adaptation, tools to support flexible planning and execution of task within systems (of systems) capable of being adapted in structure and behaviour, and tools for adaptation of systems behaviours.

Due to changing company interests, Area 2 has changed dramatically from the initial plan (with only one former company remaining active in projects). This resulted in shifting the focus from robotics (for the initial projects) more towards adaptation and flexibilisation of shop floors as well as assembly floors.

Multiple prototypes of technical results are available. A central metamodel developed within the scope of the strategic project SP2.4 for use in MFPs across the area describes shop floor actors, organisational structure, processes, capabilities, parts, and resources (e.g., tools). The model is generic and extensible enough to cover both OPC-UA centric machine control as well as manual assembly floor activities. A cloud-based assembly progress tracking and deviation dashboard supports the monitoring of assembly processes and investigating deviations in scope of MFP 2.5. The metamodel serves, among other uses, as the basis for cognitive reasoning for scheduling and flexible adaptation plan: for example, to ensure rewiring (as conducted by the Wiring Editor) are correct and complete.

Concrete results include a framework for distributed execution of production processes, described in detail in scope of project DP 2.1 as well as a framework for (self) adaptation of human-intensive cyber-physical production systems of systems. Here the accurate monitoring of assembly progress based on incomplete observations of assembly workers conducting micro-adaptations is achieved.

Positioning of the Area within the Centre

Area 2 researches the science behind the physics and logics of adaption and learning. As such, it does not concern itself with low-level man-machine interactions (Area 1) or decision support for humans (Area 3). Area 3 supports humans to understand the need and cope with the many variables that influence production, which enables humans to derive the goals. Using Area 1 man/machine interaction mechanisms, these goals are set for the machines. Area 2 thus complements Areas 1 and 3 in providing the mechanisms for adaptation, triggered by Area 1 and along dimensions and needs identified in Area 3.

EXECUTIVE SUMMARY

Area 3

Cognitive Decision Support

Area Leaders: Prof.[in] Stefanie Lindstaedt (Know-Center), Prof. Marc Streit (JKU), Prof. Tobias Schreck (TU Graz)
Area Manager: DI Dr. Belgin Mutlu (since Oct 2018, Pro²Future), Prof. Dr. Stefan Thalmann (until Sep. 2018, consulting until Sep. 2019)

Goals

Timely / Optimal Decisions - Highly complex systems often go beyond human perception and control capabilities. The Pro²Future initiative aims at supporting the handling of such complex systems via the realization of **cognitive, computational decision-making processes** to obtain optimal solutions, especially **in time sensitive situations** that overstrain the human system operator. Specifically, Pro²Future develops innovative choice modelling to enable **multi-criteria decision making**.

Beyond State of the Art in Computational Data Analytics: The crucial step beyond the current state of the art in data analytics is the requirement for **consistent analysis** and **interpretation** of **large scales** of not only **inhomogeneous data** but as well **data** of sometimes **questionable reliability** and **integrity**, which impedes **knowledge mining** as well as distinction of outliers from novelty. Hence, Pro²Future develops innovative methods for **analytic data analysis**, ranging from **visualization**, over **statistical measures** to opportunistic heuristics.

Beyond State of the Art in Computational Decision Making: The creation of choice modelling considering the multitude of decision criteria (implied sensors, actuators, resources and implications of taken actions, etc.) while still maintaining **traceability** and **transparency** of taken actions, holds a level of complexity previously unknown in the field of **industrial production control**. It is the ambition of the Pro²Future initiative to break new floors in the fields of **decision heuristics** (e.g., collective choice, voting procedures) based on **innovative decision-making methods** (Process Optimization, Prediction and Forecasting). To support human decision-making, Area 3 addresses the following two main objectives:

- combine **data-driven approaches** with configuration **management methods** and **simulation environments** in order to provide a reliable, trustworthy (data) basis for decision-making.

- Provide this objective basis for decision making to humans in such a way that it takes into account their **cognitive capabilities** (e.g., information filtering in stress situations) as well as the **situation/ context** in which the decision has to be made (e.g., within production process versus design process) in order to ensure **timely** and **optimal decisions**.

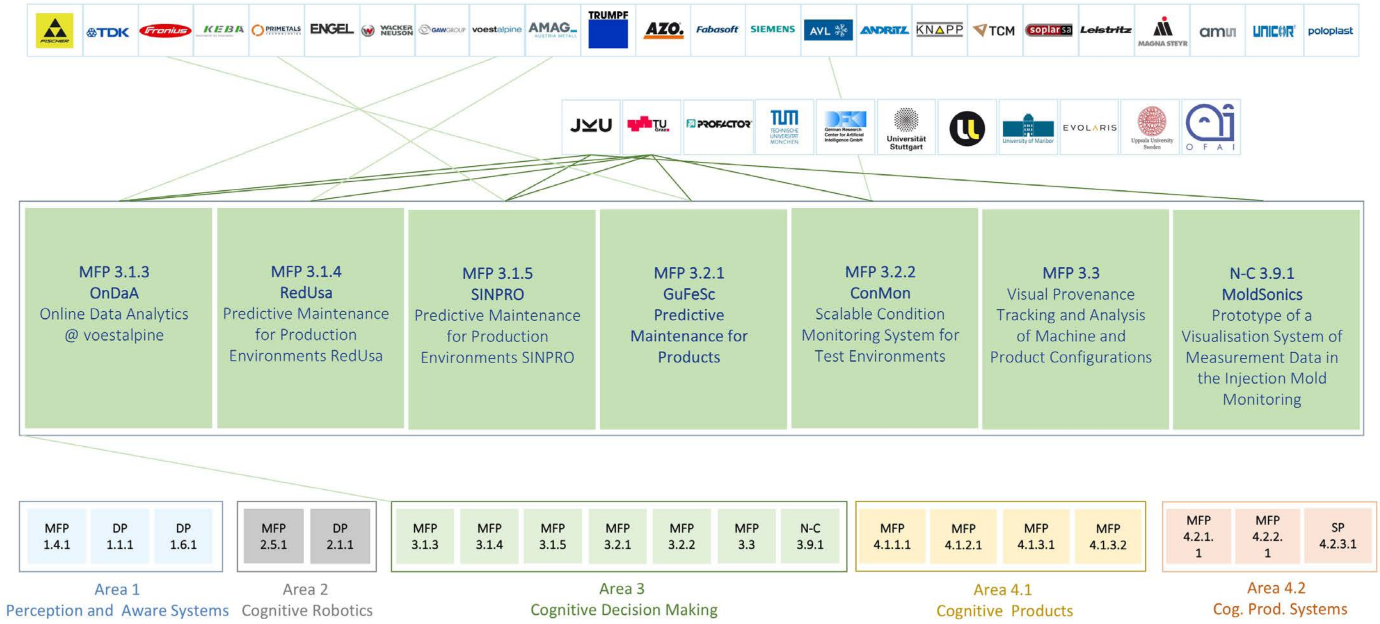
Approach

Area 3 focusses on four methodological pillars for supporting decision making of human actors: **(i) Planning**, **Scheduling** and **Supervision of Production Processes** and **Re-scheduling.** The latter can be interpreted as a re-configuration task due to dynamic requirements. **Challenges** include how to integrate **anytime aspects** into **(re-)scheduling algorithms** in order to allow **trade-offs** between **schedule quality** and **runtime performance**, and development of heuristics which allow the efficient retrieval of **personalized schedules** (i.e., schedules that take into account preferences in an optimized fashion) and how to learn them. We rely on **model-based diagnosis** to identify potentially minimal elements of a schedule that have to be adapted such that the new requirements are taken into account. **Learning algorithms** are applied for the derivation of heuristics based on a new language for the definition of **search heuristics** in the production context. A starting point to address supervision is **model-based reasoning**, which had been successfully applied to plan execution and diagnosis of automation systems.

(ii) Knowledge Management in Variability Management: The sophisticated challenges for knowledge management in industrial production of the future require further developments in the areas of **configuration knowledge representation**, **model-based diagnosis** and **testing**, **cognitive aspects of (configuration) knowledge base development** and **maintenance**, and **recommender systems**. Theories from **cognitive psychology** are analysed with regard to their applicability in the context of **configuration management**, **intelligent testing** and **debugging of knowledge bases**. Different **personalization** and **recommendation approaches** have been compared regarding their capability of **increasing** the **understandability of configuration knowledge for domain experts** (e.g., product development, marketing sales) and **knowledge engineers**.

(iii) Data-based Decision Support in Production Processes: To develop methods for efficient and effective **data acquisition**, **harmonization**, **transformation**, and **storage of data**, taking into account **security aspects and provenance information,** the work in this research topic builds heavily on methods, software frameworks, and analytics infrastructures developed in a joint undertaking with the KNOW-Center.

(iv) Visual Analytics in Production Processes To research **visual-interactive exploration methods** for p**roduction-related data (time-oriented, network-oriented data)**, tools for **visual analysis of large amounts of data** are beneficial to select appropriate data portions as input for **learning and process analysis modules** for **visual prediction tools** to be developed. To design and test visual-interactive approaches that make use of visual representations to incorporate **expert knowledge** directly into the **analysis and prediction process**,



we need to tightly integrate **automatic prediction models based,** e.g., on **time series analysis** or **classification**, with **visual-interactive data representations**.

Expected and Achieved Results

The four methodological pillars of Area 3 provide a **solid base** for implementing **predictive maintenance** and **decision making in product design** and **production processes**. It is expected that within the next 5 years the **number of sensory data** available will continue to increase significantly. Thus, it is of crucial importance that companies already explore novel ways in benefitting from this data and the insights which can be gained through its analysis. For this, it is not only important to set up the technical infrastructure to handle the data. Equally important is experimentation with the data to identify opportunities for **new or improved products** and **new services**. In order to make these **data-driven services** usable and useful for a wider user group (beyond data scientists), it is essential that the developed tools take the **cognitive strengths** and **weaknesses of humans** into account. The goal is to find an **effective division of labour** between **human** and **machine**, which synergizes the strengths of both into a productive team. In addition, we as a society have to ensure that workers (e.g., in production) have proper possibilities to build **"smart factory skills"**–to handle data and draw conclusions from it. Therefore, approaches for training and competence building interwoven with working processes appear very important.

Benefit for those applying the project results and the exploitation potential: The projects provide immediate benefit to our company partners. On the one hand, the **prototypes** can be directly **explored** and **evaluated in the work context**, thus providing valuable **feedback** both for the company as the researchers alike. Target users will be able to examine the impact from different perspectives. On the other hand, the prototypes can be developed further into specialized **decision-making tools for the industry** and thus can be exploited directly.

Area 3 contributes in two ways to the centre: (1) Development of a **methods base and computational prototypes** for providing a **reliable and trustworthy (data/facts)** basis on which decisions can be made; (2) Development of a methods base and computational prototypes for **supporting the decision making process** by taking into account **(personal) cognitive factors** of the **human, situation/context factors** of the decision making situation, and **application domain specificities** for embedding the decision-making process in the business processes.

The results we obtained have paved the way to define the preliminary **methods** for **data analytics**, and **visual data analytics** for our company partner. These methods have been developed further in the third year. To be appropriate, we have focused on **testing** and **investigating** different **AI algorithms** for (i) **forecasting** process quality, (ii) detecting **anomalies,** (iii) identifying **factors** with the **biggest influence** on the **production quality** and their **causal relations** on their applicability for predictive maintenance and decision making in production processes. For these methods we mostly used times series as input data which were **uni**- or **multivariate**. On top of that, we developed **visual analytics tools** to **monitor** the **production**- and **process data** and to **display** and **visually explore** the **AI results.** Together they defined the building blocks of intelligent decision support tools which support our company partner with maintenance tasks, monitoring the conditions of their machines and optimizing their production processes. The close **cooperation** with our **scientific advisors** from Graz University of Technology and JKU helped us to define research strategies and publish the results of the projects in peer-reviewed journals and conferences.

To stay **competitive** within the **age of AI** and at the same time to **benefit** from its **speed** and **accuracy,** our future work will focus on evaluating the applicability of **deep learning** and **reinforcement learning** algorithms in condition monitoring and predictive maintenance as well as **Bayesian networks** in analysing the root-cause of critical events in complex industrial processes. Although AI methods are increasingly being used, they are often seen as **black boxes**. For critical industrial applications with significant economic implications (e.g., predictive maintenance) this lack of transparency can be a key problem and may hinder that the AI methods are actively being used in real decision-making processes. To meet this challenge, we will further provide methods for making AI **explainable** and **understandable** to human. A special focus will be on the **explainability** of the deep-learning methods and on how to meet the constraints required for a **general application** of such methods in industry.

Positioning of the Area within the Centre

To realize cognitive products, the area utilizes concepts developed in the other areas and integrates them in the realization of cognitive product for realistic applications. A common goal of Area 1 and Area 4.1 is the development of pervasive AI, edge analytics and sensing methods. An integration of cognitive products in a shopfloor can only be achieve by integrating with efforts and methods developed in Area 2. The methods and technologies developed in Area 3, will allow Area 4.1 to realize cognition across all planned research activities and provide requirements for the development of the underlying building blocks. The cooperation with Area 4.2 allows us to establish and devise requirements for brown field integration and reasoning abilities within cognitive ensembles and combine developed technologies in the context of cognitive production systems.

EXECUTIVE SUMMARY

Area 4.1
Cognitive Products

Area Leaders: Prof. Kay Römer (TU Graz), Ass.Prof.in Jasmin Grosinger (TU Graz)
Area Manager: Dr. Konrad Diwold (Pro²Future)

Goals

The overarching **goal** of this Area is to **develop case studies for cognitive products**. Here, "cognition" denotes a product's ability to adapt its functionality across the entire product lifecycle in order to maximize customer satisfaction, product quality and sustainability, and to minimize production overheads**. Cognification** of new and existing products **requires** several factors, namely: **sensing, networking, and software platforms**. These building blocks should be both **dependable** (as many products and their production are safety-critical) and **cost effective** (as the added value of cognition must be balanced with added hardware and development costs) and will allow the design and realization of cognitive products. In order to ensure the applicability and benefit of future cognitive products and their underlying frameworks, the design and development lifecycles are realised in close cooperation with industrial partners.

As previous research into cognitive products has mostly focused on selected application domains, there is a lack of generalized, domain-agnostic solutions. Likewise, there is currently a lack of solutions that consider the entire cognitive product lifecycle. Finally, existing sensing, networking, and software platforms for cognitive products currently do not meet both dependability and low-cost requirements. Research in Area 4.1 will close this gap, by co-designing unified, dependable sensing, localization, and networking solutions, all of which will be based on radio communication.

Approach

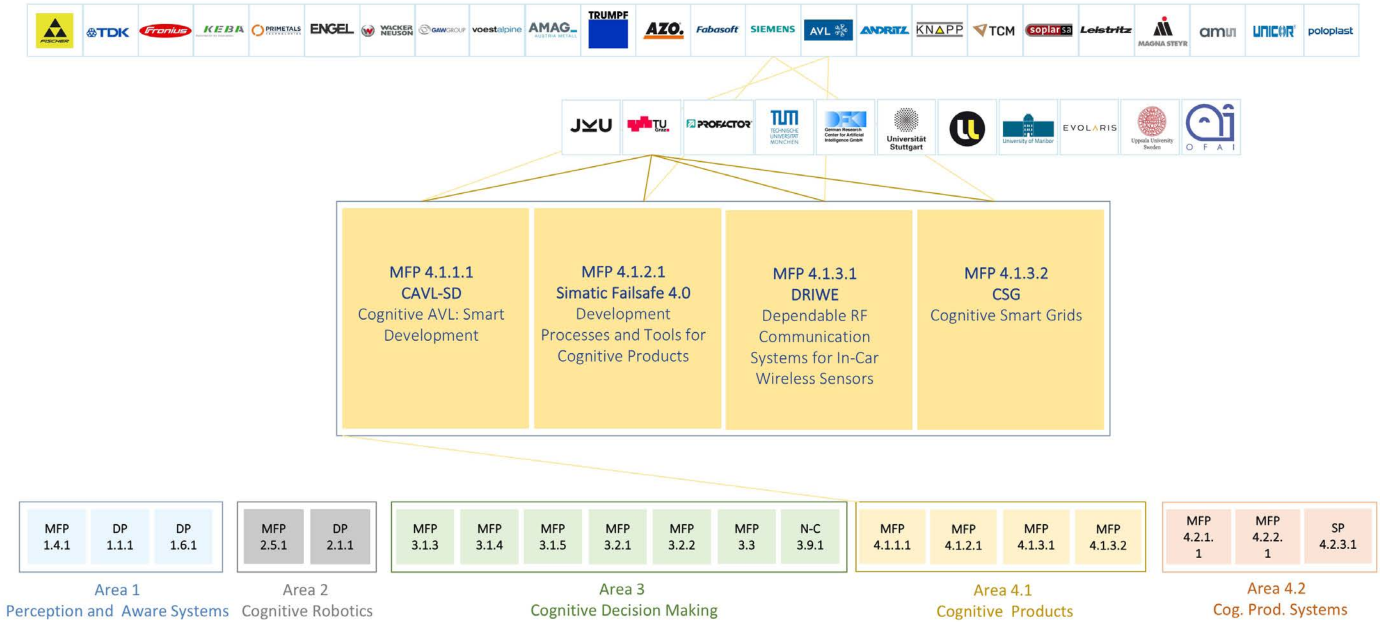
The ultimate goal of Area 4.1 is to realize **cognitive products** for **realistic applications** by **integrating concepts** from **Areas 1, 2, and 3** using novel sensing, networking, and software platforms. To achieve this overarching goal, the following objectives are addressed by the Area:

Objective 1: **Case studies of cognitive products**. The **industry partners** in the area **define case studies** in their **respective domains** in order to derive requirements on cognitive products. A **diverse set** of **application domains** are considered in order to ensure that the solutions developed in this Area are generic and can support a wide range of applications. **Prototypes** of cognitive products for the selected case studies have been realized, experimented with, and iteratively refined. The underlying methodology can be characterized by experimentally driven systems research. Previous research typically focusses on domain-specific solutions that do not generalize to other domains.

Objective 2: **Comprehensive optimization of cognitive products across their whole lifecycle.** A central benefit of "cognition" that drives the work in the Area are the comprehensive optimization of cognitive products across their whole lifecycle from **design**, **development**, and **validation**, over **production**, **use**, **service**, to **disposal** and **recycling**. Thereby, the production and use of cognitive products are **monitored** by **trustworthy embedded computers** in order to (semi)automatically optimize the hardware and the software of the products to maximize user satisfaction, to maximize product quality, to minimize the production overheads, and to maximize the sustainability of the products. Previous research focusses on selected phases of the product lifecycle and existing solutions typically cannot be extended to span the whole lifecycle.

Objective 3: **Dependable and low-cost sensing, networking, and software platforms for cognitive products.** In order to bring "cognition" into products, the latter need to be equipped with highly dependable and low-cost sensing, networking, and software solutions to realize the integrated concepts from Areas 1, 2, and 3. As many application domains of cognitive products have **safety-critical features** and the production of cognitive products is typically also a **safety-critical process**, the solutions for **sensing**, **networking**, and **embedded software** have to be **highly dependable** (i.e., reliable, available, safe, and secure) – otherwise we risk that cognitive products may fail and thereby hurt people or create economical losses. At the same time, the **extra total cost of ownership** resulting from the cognitive behaviour (e.g., additional hardware costs for sensing, networking, software; additional development costs) must be kept **low** to allow for **successful business models**. Offering dependability and low cost at the same time represents a profound research challenge, as especially the overheads for ensuring dependability result in significant costs. To this end, the Area will continue to research, among others, the co-design of unified dependable sensing, localization, and networking solutions all based on radio communication. Previous research typically focusses on individual wireless services and thus fails to exploit the potential of unified solutions.

Area 4.1 performs **experimentally driven systems research** to realize case studies of cognitive products in the application domains of our industry partners. The requirements derived from the case studies and the experience gained from experiments with the case studies drive the design of novel sensing, networking, and software platforms that **bring cognition into products** and enable their comprehensive optimization across their whole lifecycle. Specifically, three multi-firm projects (MFP) and one strategic project (SP) have been defined. **MFP 4.1.1 Comprehensive Optimization of the Cognitive Product Lifecycle** investigates novel architectures and solutions for comprehensive optimization of cognitive (Area 4.1 objectives 1 and 2). **MFP 4.1.2 Development Processes and Tools for Cognitive Products** investigates



software development processes and tools for cognitive products (Area 4.1 objectives 1 and 3). **MFP 4.1.3 Internet of Cognitive Products and Production Systems** focuses on (inter)networking cognitive products and production environments (Area 4.1 objective 1 and 3). **StratP 4.1.4 Unified Dependable Wireless Services for Cognitive Products** investigates co-design sensing, networking, and localization approaches all based on radio communication in order to maximize dependability of these wireless services while at the same time minimizing their cost.

Expected and Achieved Results

The area aims for prototypes of **cognitive products** for **realistic applications** realized on top of low-cost and highly dependable sensing, networking, and software platforms, integrating concepts from Areas 1-3. Specific technical results include a **trustworthy platforms** for **sensor data acquisition** from cognitive products; an **engine** for **mining sensor data** from cognitive products; **decision support tools** for the **human product designer**; **software development processes** and **tools** for cognitive products; **architectures** and **protocols** for an i**nteroperable** and **highly-dynamic Internet of products** and machines; **tools** for **automatically placing software functions** in the Internet of products and machines; and a **unified set** of **dependable wireless services** (sensing, networking, localization).

A **key benefit** is that the developed platforms for cognitive products will have a dependable performance even in **harsh industrial environments** and can thus be employed even **for safety-critical products** and their production. In addition, the performance of the resulting cognitive products will have to be **predictable before actually deploying** them. These are crucial prerequisites for realizing cognitive products in critical applications where **failures** may have disastrous consequences. A further key benefit is that the platforms will be **cost-efficient solutions**, such that employing the results of Area 4.1 will have a limited impact on the price tag of cognitive products. This is a crucial prerequisite for many business models involving cognitive products.

Area 4.1 has been substantiating the three MFPs that are associated with Cognitive Products and their life-cycle and have been pursuing basic research on enabling technologies for industrial integration scenarios on all levels of the networking stack as part of the strategic project. In the context of **MFP 4.1.1 Comprehensive Optimization of the Cognitive Product Lifecycle** a framework for the **semantic modelling of production development process** was developed which enables **reasoning** with our **Company Partners AVL List GmbH**. In addition, methods to **interface semantic web technology** with **machine learning** were developed to enable a semantically driven life cycle optimization with machine learning classification capabilities. Together with our company partner **Siemens AG Austria** we investigated in **MFP 4.1.2 Development Processes and Tools for Cognitive Products** how **functional safety, availability, and maintainability** can be **improved** in industrial environments. During the project, **a novel dynamic safety concept** which allows the dependable **cooperation of robots and machines in a production environment** was developed and demonstrated at the Austrian Village at the European ICT 2018. In addition, several **novel failsafe methods** have been **developed** and demonstrated, such as **two new soft-error mitigation strategies**. The MFP also demonstrated how **low-cost IoT** hardware can be used to **extend existing automation devices** with **cognitive features** (such as awareness), which allows the implementation of **novel cognitive services and features.**

Together with our company partner **Siemens AG Austria, AVL List GmbH and HMI Masters GmbH** we investigated in **MFP 4.1.3 Unified Dependable Wireless Services for Cognitive** Products dependable communication strategies for cognitive products and production systems. As a result, methods for the **simulation-based optimization of in-car communication systems** were developed, which utilize ray tracing in combination with link budget calculations to derive an **optimal setup** (antenna type and position) given a **specific target environment**. In addition, a recommender system was developed to identify optimal communication protocols to realize a particular use case. The project also demonstrated a concept for **BLE-based monitoring**, which requires **minimal engineering effort** and developed tools for the management of **communication in dynamic environments**, by assessing current **available link qualities (across multiple radios)** and **adjusting** the used communication channels and **payloads accordingly to achieve robust and dependable communication.**

Positioning of the Area within the Centre

Area 4.1 is one of the two application-oriented areas and thus forms a central integration point in the Centre. The Area integrates concepts from Areas 1-3 and applies them to the realization of cognitive products for real-world applications. Industry partners will provide these case studies. By carefully analysing and conforming to the requirements of these case studies and of the concepts from Areas 1-3, the sensing, networking, and software platforms will be tailor-made to enable in-product cognition appropriate to the case studies. At the same time, the multifaceted character of the case studies ensures that generalized solutions will be devised that suit a wide spectrum of cognitive products across their entire product lifecycle. The role of products in their production environment (which is the topic of Area 4.2) is also highly relevant and thus forms a cross-Area link.

EXECUTIVE SUMMARY

Area 4.2
Cognitive Production Systems

Area Leaders: Prof. Kurt Schlacher (JKU), Prof. Franz Haas (TU Graz), Prof. Rudolf Pichler (TU Graz)
Area Manager: Dr. Markus Brillinger (Pro²Future), Mag. Bernhard Löw-Baselli (JKU)

Goals

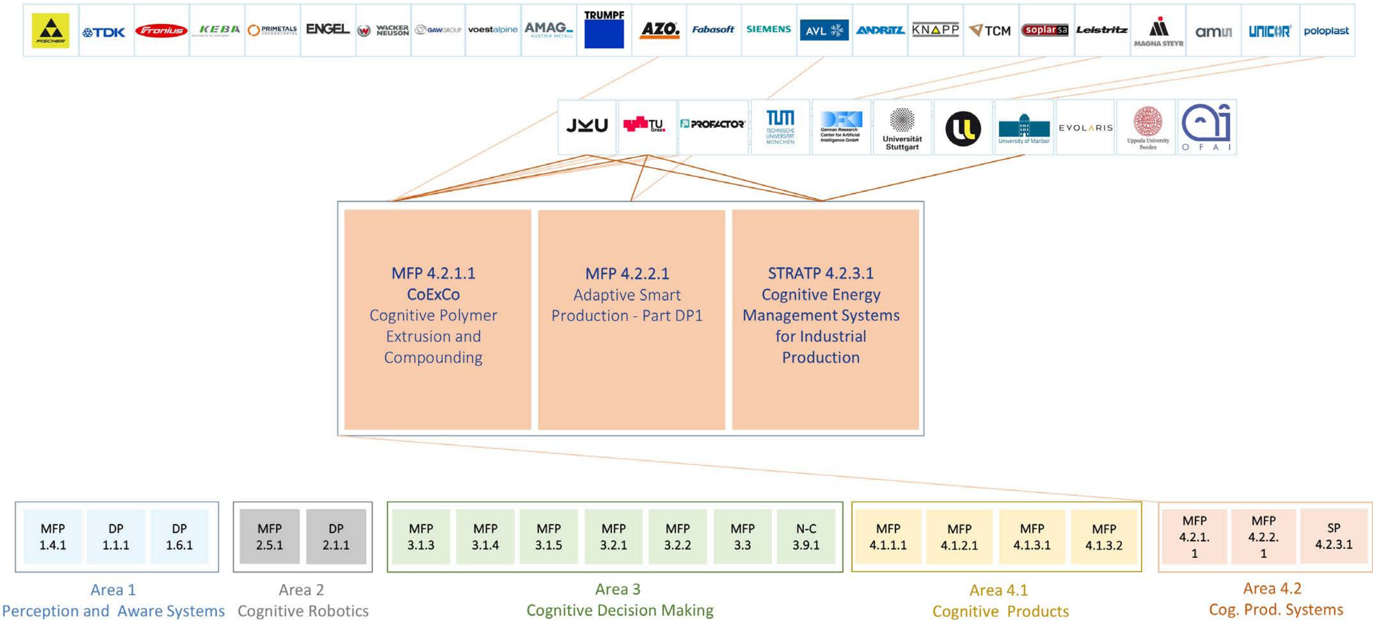
Cognitive production systems represent a significant step beyond current state of the art due to their ability to self-adapt, interact and integrate with human-like flexibility, reliability, autonomy and robustness. Cognitive production systems will be able to reason from collected data; perceive, process, and interpret information to generate responses, actions and reactions, learn new models and self-adapt the existing ones; communicate and interact with other systems and humans, and be able to plan. In addition to this, the systems should behave adaptive to different production scenarios.
One import goal is for example to handle non steady state cases including the ramp up phase, which becomes dominant, whenever more diversified and fast changing product portfolios are required. One has to preserve tight quality tolerances, increased energy efficiency, as well as reduced waste and environmental impact under volatile energy and raw material prices.
A tight cooperation between the involved engineering sciences is necessary to succeed. A precise mathematical description of the processes allows already today monitoring beyond simple data processing. It is the indispensable tool toward awareness, process and product intelligence. This description must be extended such that the models become applicable to the problems caused by the new technologies. Basic algorithms like for control, monitoring etc. must be revised or replaced by new ones, such that distributed sensor and actuator fields can be handled, whereat the communication efforts are minimized, data security is granted and the current high level for services remains. This includes non-linear model predictive control, as well as smart data predictive control. All investigations must be performed with a strong view to application scenarios like the factory in the factory, as well as to the introduction of methods new for the application under consideration, like big data analysis, see Area 3.

Approach

Area 4.2 investigates principles based modelling for analysis, system design and automatic control, like non-linear model predictive control technology including big data analysis driven optimisation of the overall plant dynamics, specific in-line process monitoring technology, as well as human-machine interaction with 3D motion tracking technology. The work program for batch production is the setup of a Smart Factory at Graz University of Technology and for continuous production is set up on Living Lab at Johannes Kepler University Linz. These will be the places, where defined topics of research and tests of all the new ideas mentioned before will be executed and evaluated. The pilot factories at Graz University of Technology and Johannes Kepler University in Linz will show the production of the future using emerging technologies, e.g. automatic guided vehicles (AGVs), 5G and cloud computing.
The management of complex situations (non-steady state cases) like change of operating points, (ad hoc) set-up and tracking of new trajectories, monitoring is a natural task of the cloud. The required mathematical models and tools, the algorithms and software systems will become available for the user, where the use of open software is preferred, such that monitoring, big data analysis, selective diagnosis etc., become possible beyond the current industrial standard. Cloud fog models of production processes lead to new business models because they break the current spatial connection between machines and control devices. Particular for control in the broader sense of guidance, on line optimisation, adaption etc. one will be to check proposed new models with respect to economic feasibility, but also to reliability, data security, and others.

Expected and Achieved Results

- Novel detection methods for human factors (vital state, skill, stress, peripheral interrupts) to reduce the workload and decrease the risk of incorrect operation.
- Novel concept for experimental and computational modelling of cognitive self-optimisation polymer extrusion and compounding production for increased production productivity and product quality.



- Novel meta-heuristic mathematical models of real time production including big data.
- Novel smart data and first principles based predictive control technologies.
- Enhanced on-line molecular mass control, in-line bulk material feeding and ramp up of working point.
- Implementation of a modular, opportunistic assistance recognition architecture making use of dedicated sensors.
- Smart batch production by modularization, simulation and virtualization.

In Area 4.2 two multi-firm projects (MFPs) were executed during funding period 1 until year 3 which started both in year one.
Cognitive Polymer Extrusion and Compounding CoExCo (MFP 4.2.1) has started as multi-firm project with the Company Partners AZO, Leistritz, and Poloplast but in difference to the proposal with Unicor (which has undertaken tasks of their company holding GAW) and Soplar instead of Tiger (which has retired before signing the contract). The project Adaptive Smart Production ASP (MFP 4.2.2) includes only a use case with AVL, because SFL technologies GmbH has also retired before signing the contract due to insolvency.
In the first year of the two projects, we were setting up network connections to our partners, as well as gathering and evaluating data. During the second year, we continued with data mining, deduced data-based models, and cognitive production systems for continuous (MFP 4.2.1) and discrete (MFP 4.2.2) flow of material. In the third year, we implemented the deduced data-driven models into both pilot factories, Linz and Graz. During the ongoing fourth year, we are testing, evaluating and refining these models.
On an employee level, in Area 4.2 currently 7 researchers are employed, named Markus Brillinger, Raffael Rathner, Muaaz Abdul Hadi, Maximilian Zacher, Marcel Wuwer, Hanny Albrecht and Johannes Diwold.
To sum up, we can conclude Area 4.2 achieved a good start. Due to some personnel changes up to highest level at JKU-ipec MFP 4.2.1 has had mayor disruptions at the end of 2018, but new highly skilled employees were found. However, one workpackage in project CoExCo with company Poloplast were under reconfiguration. Nevertheless, the positive feedback of the ongoing results of all other Company Partners contributing in Area 4.2 allows us to look favourably into the future.

Positioning of the Area within the Centre

The Area 4.2 "Cognitive Production Systems" deals with the central question of upgrading production systems, design of structures for information processing in terms of cognitive skills, as well as the deduction of new business models enabled by the approach of cognitive factories. Area 4.2 will strongly interact with the other areas and should finally demonstrate the performance potential of next generation production systems by means of (i) real pilot living labs, especially for continuous operating production processes like polymer extrusion and compounding as well as (ii) a real "smart factory" for batch production.
In contrast to the other areas the research core of Area 4.2 lies on the one hand in engineering science (the research results of Area 4.2 itself) and on the other hand in the symbiosis of computer science/ mathematics (the research results of the other areas) with engineering science.
Engineering sciences of Area 4.2 are: (i) **automatic control**, which covers principles and methods to analyse and design software systems for complex network controlled feedback systems, including, monitoring, optimisation etc. (ii) **polymer processing technologies** which cover computational and experimental engineering activities concerned with operations carried out on polymeric materials or systems to increase their utility, the efficiency in production and to save resources as well as (iii) **flexible automation and robotics**, AGV, cloud computing and 5G - technologies and an open communication/interaction standard of all the participating specific machinery for realizing the framework for a highly flexible batch-size-one production.

EXECUTIVE SUMMARY

Area X
Common Research Programme on Cognitive Industrial Systems

Pro²Future has been collaborating with its sister COMET K1 Centre "Center for Digital Production" (CDP). This common research activities have been established in a more formal manner as a Common Research Programme (CRP). The CRP provides the frame for multiple demonstrator project(s) between Pro²Future and CDP. These demonstrator projects – for the period of the first two years – have to amount to a minimum volume of 2.4 Mio. EUR from each centre.

Pro²Future's main research and R&D emphasis is on **cognitive products** and **production systems**, and the **CDP** COMET K1 Centre is working on challenges posed by the fourth industrial revolution (Industry 4.0), requiring manufacturing companies to support a seamless integration of all process steps including automation, control and documentation. CDP covers process steps ranging from acquisition to delivery: (i) the **virtualisation of product and production systems** to allow for a comprehensive product specification and a reliable process planning, (ii) the **development of design automation** to not only accelerate the design process but also the work planning, (iii) **protocols for machine-to-machine communication** to support the implementation of flexible and reconfigurable automation systems, (iv) **digital platforms and networks for production** to allow for the dynamic formation of virtual smart factories enabling low tier manufacturers to provide a combined and therefore value-added service, and (v) the **ergonomic, legal and socioeconomic impacts** of digital production. **Their main R&D emphasis is on systems for digital production**.

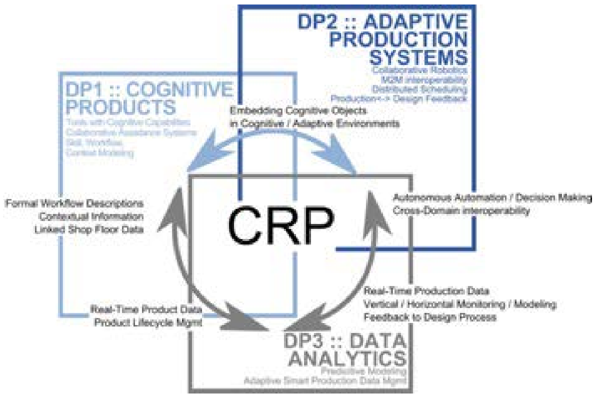
The **Common Research Programme (CRP) on Cognitive Industrial Systems** was developed in a structured solicitation process, including industrial partner of both consortia and moderated by the „Plattform Industrie 4.0 - Österreich" (https://plattformindustrie40.at/). In this process, significant technological and industry relevant problems were identified that will foreseeably challenge Austria's industry in near future and problem categories were shaped in line with the solution competencies coming from both consortia. The priorities that were deduced from topical industrial needs, aim at fostering innovation and competitiveness of Austria's Industrial Sector in international markets. In short, research priorities have been set towards (i) the **embedding of cognitive abilities** into products of the future, (ii) the **autonomous adaptation of modular production systems and supply chains** enabling manufacturing aiming at highly adaptive, and improved quality production processes, and (iii) **entangling product life cycles** and product use patterns **with processes and workflows** in adaptive and interoperable manufacturing systems based on **semantic and interoperable data flows and predictive analytics distributed on edge and cloud-based systems**. Industry 4.0 research at CDP in conjunction with the Cognitive Products and Production Systems research at Pro²Future paved the way towards a confluence of Industry 4.0 Systems and Cognitive Systems, suggesting headlining the Common Research Program (CRP) as Cognitive Industrial Systems.

The Common Research Programme has allowed to aggregate complementary approaches of Pro²Future and CDP into a joint, synergetic research initiative, extending the outreach for both centres, and stimulating research supporting Austria's manufacturing industry. For this purpose, three demonstrator projects have been developed, with prototypical realisations, demonstrating the potential and functionalities in the fields of (i) **assistive man-machine collaboration** (equipping machines with collaborative, cognitive capabilities to provide optimal worker support, as well as providing work tools and instruments with cognitive features to assist complex work processes with assistive guidance), (ii) **adaptive control and dynamic adaption of networked production** (enabling edge and cloud based intelligent cyber physical systems) as well as (iii) **integrated data analytics** (to allow for autonomous, sensor based data collection, mining and knowledge extraction, prediction and forecasting, planning, optimisation, autonomous decision-making and real-time control and steering).

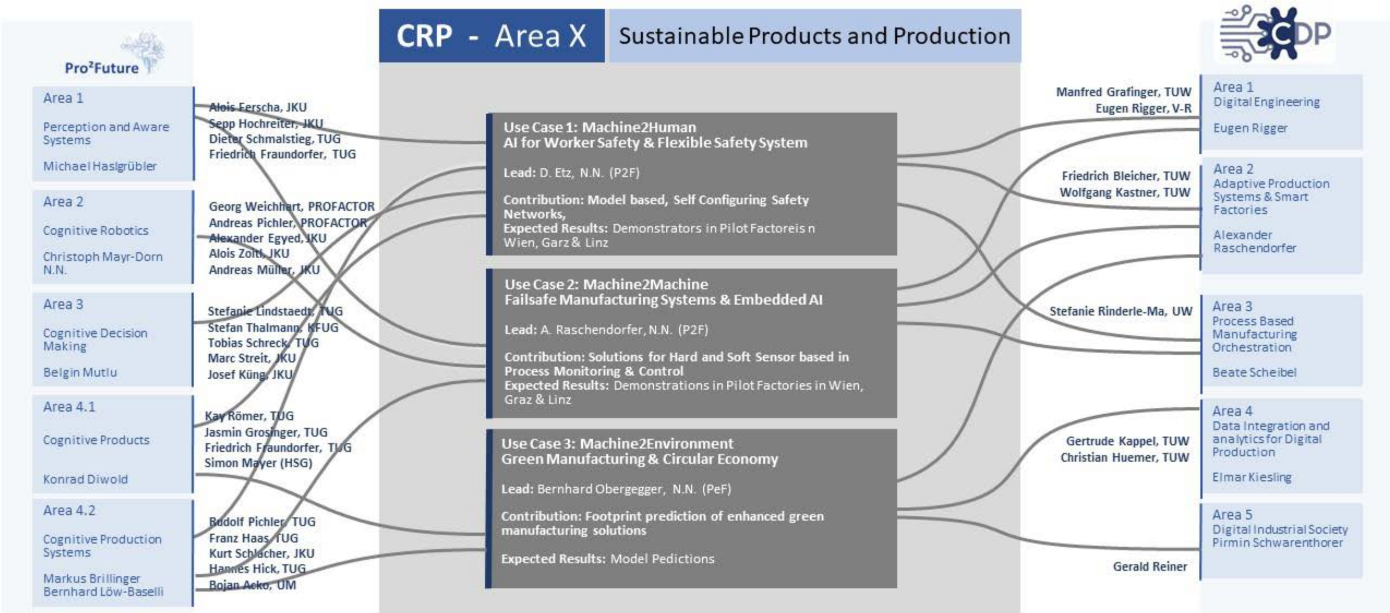
The Demonstrator Projects (DPs) are intended to demonstrate the potentials of online, real-time, interoperable, semantically structured **data and meta-data exchange** among **products**, **workflow systems** and physical **manufacturing systems**, so as to show-case adaptivity of product features and abilities, tools and work instruments, robotic equipment, manufacturing machinery, shop floors, from a continuous **feedback-loop among products and production systems**. It is considered ultimately important to exemplify projects that not only show how future and emerging industrial technologies impact the design, creation, use and life cycle of **products on their own**, and how these advances will excel how industry plans and sets-up production equipment and **manufacturing lines on their own**. CRP aims to clearly pose a case demonstrating **next generation products and production sys-**

tems. We shall demonstrate by example how cognitive product use impacts the next generation of tool designs by collecting, analysing and mining **product use data** , how tool-use intertwines with manufacturing processes that build on human-machine collaboration and enable higher levels of **adaptation in production**.

The Common Research Programme aims at exploring the potentials in the fields of (i) **physical cognitive products** in the realm of an intimate man-machine interaction which interact and correspond to workers and other cognitive systems in the direct environment, (ii) **adaptive machine-to-machine production systems** for optimized, synergetic organization of automatable tasks as well as (iii) **advancing required approaches for data analysis** which are capable of specifically contributing to improving production processes.



Entanglement and Overlap of the Demonstrator Projects (DPs) contributing to the Common Research Program (CRP)



The CRP is implemented in a **two-phase approach**. **Phase 1** (project years 1 and 2) will bring (according to the assessment of industrial partners very challenging, and very concrete) the demonstrator projects (DPs) **DP 1 - Cognitive Products, DP 2 - Adaptive Production Systems**, and **DP 3 - Data Analytics for Industrial Process Improvement** to a level of convincing "proof-of-concept" systems. In **Phase 2** (project years 3 and 4) they will be raised to fully functional, self-contained, highly elaborated, convincing demonstrators.

To approach the identified challenges, the consortia decided on **three representative demonstrator projects** that overlap in the data generated and exchanged for enabling the proposed functionalities as individual projects as well as an overall functioning single demonstrator, fusing the developments into an overall vision of future production systems.

DP1 - Cognitive Products addresses the aspects of realizing physical instances of direct, man-machine collaboration realising human-centred assistance systems.

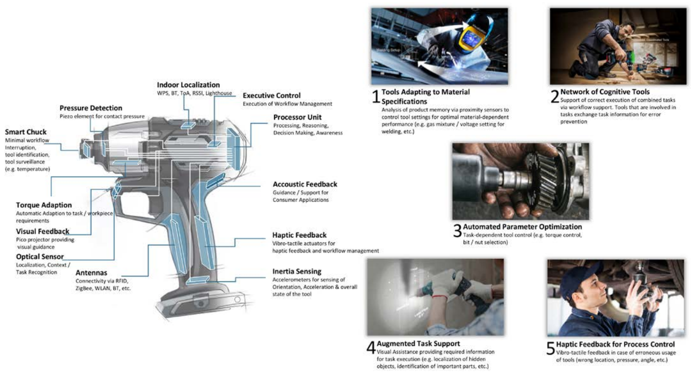
DP2 - Adaptive Productions Systems aims at demonstrating solutions for self-adapting production systems and focusses on collaborative robotics, distributed scheduling of adaptive shop floors as well as feedback of production data into the design process.

DP3 - Data Analytics for Industrial Process Improvement will cover the fields of integration of processes, data analytics, and simulations and will build a toolset (set of algorithms, analytic machinery and visualisations) for industrial process improvements based on data analytics, to be evaluated by specific use cases in the Smart Factories in Austria. These three demonstrator projects overlap in the data generated and exchanged for enabling the proposed functionalities as individual projects as well as an overall functioning single demonstrator, fusing the developments into an **overall vision of future production systems**.

EXECUTIVE SUMMARY

DP 1

Cognitive Products



The current trend towards individualization of products is creating a dichotomy of automation and revival of manual labor in industrial production. Due to their **cognitive capabilities**, humans are better in adapting to changing, customized manufacturing processes than fully automated mass production systems. However, to maintain manufacturing efficiency, the **increasing specialization of products** and processes **requires guidance in task execution**. Furthermore, industrial companies nowadays recognize the benefits of a continuous, detailed assessment of current processes and their respective data for optimizing product specifications and production via digitalization of (semi) automated processes. DP1 attempts to advance the state of the art by digitizing **manufacturing processes that involve the human worker** and providing worker support with all associated complexities. The development of **cognitive manufacturing tools** (i.e. PowerTools) to enhance the performance of workers within a smart factory is hereby the chosen modality.

DP1 addresses these issues via the development of cognitive products, which are created by **embedding AI principles** into product hardware, and advanced machine learning and pattern recognition techniques into the software. These products thus **integrate cognitive functionality**, such as **perceiving** situations and the environment, **learning** and **reasoning** from knowledge models. The ultimate goal is to turn machines into ones that can reason using substantial amount of appropriately represented knowledge, learn from its past experiences in order to continuously improve performance, be aware of its own capabilities, reflect on its own behavior and respond robustly to surprise. Currently, we are witnessing an era in which the convergence of algorithmic advances, data proliferation, and tremendous increase in computing power and storage have propelled **Artificial Intelligence** (**AI**) from hype to reality. However, in order to develop truly cognitive learning and thinking machines there are open key challenges to address, i.e., (i) machine learning requires massive resources (computing power and training data), (ii) models do not generalize well, (iii) and processes of training and inference most likely differ from human learning and reasoning. Gaps we aim to reduce or even close with DP1.

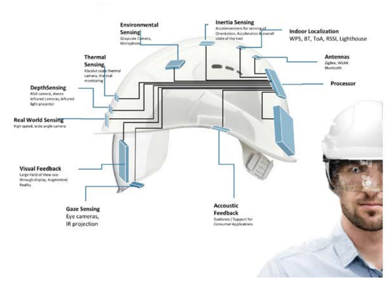
Goals

DP1 has addressed key challenges towards this vision by **embedding cognitive capabilities,** such as perception, reasoning, learning and planning, into production tools in order to enable advanced (i) Worker **Guidance** and Support, (ii) **Automated Tool Configuration** and **Workflow-**adaptation, and (iii) **Data Collection** for Modeling and Documentation of Production Front- and Backend Processes by embedding sensor, actuators and reasoning systems (e.g. machine learning) into tangible objects operating in the real world, in our case, particular in production environments.

The **selection of production tools as instances of Cognitive Products** (i.e. PowerTools) was driven by (i) their direct applicability to existing R&D environments in the industrial consortium, and (ii) due to their potential to bring a competitive advantage for industrial players: Cognitive Products provide key benefits, such as (i) **learning from past experience** to avoid repetition of errors and continuously improve quality and cost, (ii) production **task awareness** to enable flexible adaptation to variations within a single and across different tasks, (iii) **worker skill awareness** to enable compensation for lack of skill or attention, and (iv) **collaboration** between cognitive tools to provide resolution for deviations in earlier production steps. DP1 approaches these issues by means of visual/multi-sensor data analysis using deep learning and other modern (un)supervised classification, prediction and learning methods.

Thus, DP1 continuously aims at provisioning cognitive behaviors to industrial production processes as well as to end-user application scenarios. In particular, the project activities are focusing on the objectives of CRP: (i) develop new and enrich existing industrial **tools with cognitive capabilities,** (ii) optimize tool utilization and production processes based on **device state and contextual information** (iii) detect **cognitive load and attention** level and adapt the manufacturing process and (iv) identify **experience/skill level and workflow complexity** and adjust the worker's assistance appropriately.

We designed DP1 around 7 demo cases (DP1.1-DP1.7) show casing **solutions for cognitive products: DC 1.1:** Built upon state-of-the-art design tools enhanced and **novel realizations** interlinking existing production hardware with modern sensor and actuator hardware, and implemented **cognitive, (pro)active software modules** complying with the requirements of specific application scenarios, **DC 1.2:** Designed and developed a functional prototype of a **cognitive, head-mounted welding gear** and the associated design and implementation toolchain, demonstrated in a **digitalization scenario** of analog factories **DC 1.3:** Mobile eye-tracker based on fixations, saccades, blinks, pupils and smooth pursuit for detecting **cognitive load, skill and attention** level, **DC 1.4:** Multi-sensor fusion **framework** providing algorithms for **work-step and micro-action detection** aiming to provide appropriate worker guidance. **DC 1.5** (extending **DC 1.1**)**:** Develop manufacturing equipment, such as **cordless screwdrivers**, to be used in the production line of our industrial partners, where such equipment is used on a regular basis, **DC 1.6** (deepening **DC 1.1**)**:** Develop **unified dependable wireless services and communication platforms** enabling the respective products and tools to collaborate, and position themselves using batteryless radio frequency based sensing, **DC 1.7** (extending and specializing if **DC 1.3** and **DC 1.4**)**::** Develop **self-learning** adaptive control for **cognitive welding machines**.



The project results so far were demonstrated by means of a **Cognitive Welding Machine** as first instance of a dedicated CP showcase on the feasibility of the approach. The found principles were already extended to other domains, e.g. **power tools, heavy machinery**, or **assembly process** with respect to the company partners. Beyond this **refinement of the principles**, a particular focus will be to foster the **embedding** of **dependable wireless services**, and establish where **high bandwidth communication** and **low latency** is of concern. Additionally, **safety** and **security** will be embedded into the components to provide **content security**, **anonymization** and **privacy by design**.

Approach

Building upon the approach of opportunistic sensing, **cognitive components** will be made capable of **describing their capabilities** with respect to both sensing and actuating. They are able to find each other, form collective ensembles in a **self-organizing** manner and exchange structured data. **Collectively**, they will **sense the current contextual state**, in which they are used and adapt themselves accordingly, for example pre-emptively by suggesting usage strategies or best practices to the users, as well as reactively by setting operation parameters to suit the circumstance. Finally, the ensemble will be able to **learn from usage**/misuse of individual tools in the collective and take re-/proactive steps to increase their own life span or avoid hazard situations.
The consortium can build on rich experience from the fields of: advanced, opportunistic, **multi-sensor fusion** in embedded recognition architectures; **collective ensembles**, context- and activity recognition, attention recognition, behaviour prediction, **assistive multi-modal** systems; design of dependable wireless ICT platforms. Integration of the domain specific methods and tools for mechanical design, electrical/electronic engineering and software development is one main challenge in creating complex technical systems. For the development and engineering of the demonstrator within the project, latest **multi-disciplinary engineering design** methods will be applied. The methodical basis is set by VDI guideline 2206 but also **agile** approaches to **engineering design**, taken over from software development will be deployed.

Expected and Achieved Results

So far, an ensemble of cognitive components has been embedded into a three-folded welding gear, consisting of a welding shield, a welding torch and a power source and cognitive power drill, enabling the overall system to **present cognitive capabilities,** such as, perception, reasoning, learning and planning, towards its users. So far, the cognitive power tools are able to (i) support Worker **Guidance**, (ii) provide **Tool Configuration** based on the selected or detected step in a **workflow**, and (iii) provide **data recording capabilities** for documentation of overt and implicit production behavior.

Four **Demo Cases** have been accomplished so far in the executing **MFPs** WorkIT, GUIDE, SeeIT on the Pro²Future side, and **MFPs** MFP33, MFP11 on the CDP side: In **DP1-DC 1.1 :: Cognitive Product Design** three engineering design support features have been developed. The first one is a cognitive element library for SolidWorks enabling the re-use of common cognitive parts. The second is a CAD plugin facilitating the link of non-geometrical information (e.g., requirements) to CAD models that may be built with cognitive library elements. Thirdly an extraction tool supporting the creation of software configuration files, which include data originating from the model. For **DP1-DC 1.2 :: Digitalization of Industrial Environments** we saw that indoor localization based on infrastructure sensors was not feasible due to arbitrarily complex, large environments with mobile actors. In order to create and continously update point cloud models of arbitrary environments on-the-go, an image-based approach built upon a head-mounted RGBD camera and the RTAP-Map framework was used. For **DP1-DC 1.3 :: Gaze-based Skill-level Detection** a mobile eye-tracker was employed to create a labeled task-dependent training data set. The training samples were segmented, an extensive feature set based on fixations, saccades, blinks, pupils and smooth pursuits was extracted and used for model training. At runtime, the sensor data is again segmented and extracted features are classified by the trained model**. In DP1-DC 1.4 Work-Step Recognition** we built a dedicated software platform with capturing support for various sensing devices and supporting multiple operating systems and hardware platforms. Further, algorithms for multi-sensor fusion that are able to detect worksteps and micro-actions and that show the current state of the worker within a workflow model were developed. Based on the current workstep the system provides dedicated help to guide the user. For **MFPs** follow up results are in progress in the **Demo Cases DC 1.5** (extending **DC 1.1**)**: Develop manufacturing equipment**, **DC 1.6** (deepening **DC 1.1**)**: Develop unified dependable wireless services and communication platforms**, and **DC 1.7** (extending and specializing **DC 1.3** and **DC 1.4**) Develop **self-learning** adaptive control for **cognitive welding machines**.

As **overall DP1 achievement** (i) **quality control** has been digitalized & integrated into the assembly procedure (SeeIT; CP KEBA), (ii) well-defined **formal and visualizable workflows** established (WorkIT, SeeIT; ECB TRUMPF; ECB Fronius), (iii) **reduced cognitive strains on workers** induced by continuous and repetitive work processes (workIT, GUIDE; CP Fronius; CP TRUMPF), (iv) exploited **acceleration potentials by Just-in-time assistance** in cognitive product (power-tool) handling and lot-size-1 production (GUIDE; CP KEBA; CP Fronius), (v) aligned with cognitive power-tool features, by **providing cognitive guidance for workers** (GUIDE; CP TRUMPF; CP Fill; ECB ModelWorks), (vi) created **training** of human workers **at the workplace "on-the-fly"** (GUIDE; CP Wacker Neuson; CP: Trumpf/KEBA), (vii) practiced **Cognitive Welding Support** practiced with the HeadGear platform (presented at HANNOVER MESSE 2019). This resulted in **13 Peer-reviewed publications (2 co-authored Pro²Future / CDP, 1 co-authored with industry), 2 PhD approved (5+2 PhD in progress)** and **3 Masters (5 Masters in progress)**, and the international conference **IoT 2017 organized** and **hosted** at **JKU Linz.**

EXECUTIVE SUMMARY

DP 2

Adaptive Production Systems

(Not only) the 2020 pandemic has shown the importance of being able to have production systems in the heart of Europe. Physical Production around tangible goods is essential for jobs, welfare and social sustainability. In Europa competitive advantage is enables by agile production in a high mix, low volume environment. These requirements concern SMEs as well as large OEMs in Austria. Recent developments, subsumed under the headings of "Industrial Internet of Things" (IIoT), "Industry 4.0" (I4.0) and "Cyber Physical Production Systems" (CPPS), address the ability of machines to interact interoperable as a complex, adaptive network. While individual and isolated interface technologies and approaches exist, for a flexible network of production systems, several important elements are still missing and sustained research is necessary.

Through the incorporation of Industrial Internet of Things (IIoT), Cyber Physical Systems (CPS), collaborative robots (Co-Bots) and Edge/Cloud-computing into the entire production process, small-lot-sizes, speed, efficiency, quality is addressed altogether through an adaptive production system. The adaptive production system combines conflicting paradigms of flexibility and efficiency amid high quality.

The goal of the demonstrator DP 2 is to realise proof-of-concept implementations and industrial application examples by incorporating results of the research activities into regular operations. Prototypes will be provided on a ready-to-use level of maturity in order to prove industrial relevance.

Specifically, in DP 2, Pro²Future is closely collaborating with DP 2-leader CDP (Pilotfabrik Aspern), to demonstrate IT technology in the context of the milling process, intelligent fixture, flexible milling process and adaptive robotic systems. Hence, the following describes the overall project, but the Pro²Future team contributes not to all of the following goals.

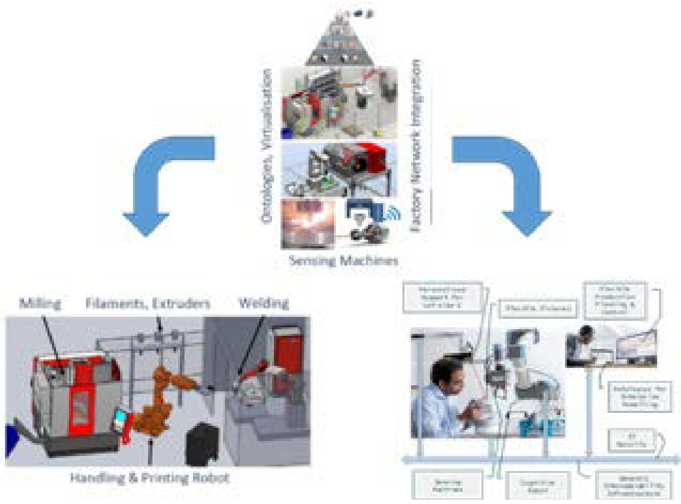
Goals

The overall objective is to demonstrate that adaptive production systems can be implemented by modern factory network and process control architectures for both fully automated process execution and manually assisted process execution.

For this purpose, the demonstrator DP 2 will implement a factory network based on OPC UA and workflow engines, in order to be able to implement plug and produce capabilities. This includes the composition of formerly distinct production units to a new, combined machining system.

The commonly developed flexible infrastructure enables multiple scenarios, which range from fully automated processes to collaborative robotics. In both cases, an infrastructure building on ontologies will provide a semantic layer that allows connecting multiple systems and processes. The figure below depicts this approach and it shows demonstrators that focuses on an automation scenario and a demonstrator that focuses on human worker support.

The figure separates the common research on the "middleware for the networked Production Systems" providing the input for demonstrators at different locations and where more specific research takes place. It is also the basis to feed production process data back to the design process.



3.2.2 Researched flexible Infrastructure feeding the Demonstrators

Approach

For design and implementation of OPC UA interfaces for demonstrator a systematic model driven approach is used. The main idea is to separate the design system from the implementation. The OPC UA interfaces will be described by using OPC UA modelling language, which is based on UML and afterwards code fragments for runnable applications will be generated automatically.

An OPC UA stack has to be developed in which TSN (Time Sensitive Networks) can be used concurrently with classical Ethernet as data link-layer. Based on the stack, both an appropriate OPC UA server and client implementation are required to meet the requirements of TSM. This approach allows making use of real-time communication while preserving compatibility with other OPC UA enabled manufacturing machines, and making these in an IT-friendly way interoperable with SCADA, MES and ERP environments. Transferring process data generated by sensing and tweeting machines back into the automated design process will enable product improvements in terms of, quality and cost through design for manufacturability.

For modelling an ontology for semantic interoperability, OWL will be made interoperable on the data-level with OPC UA Information models. Available interoperability tools will be analysed and a suitable tool will be chosen and adopted. Finally, the information models and queries will be implemented in OPC UA servers of the devices in the demonstrator.

Continuous adaptation requires interoperability of systems. Collaborative Robots require access to information from heterogeneous systems. This requires that the robot is aware of the above semantics of the information from the heterogeneous software environment and workflow. The robot requires its own interpretation engine. In addition to this general understanding of the work tasks, is it required to merge sensor data with the "static" knowledge-based models. This, includes, but is of course not limited to, the identification of product parts and the human operator manipulating parts. A basic understanding of critical situations with respect to inconsistencies of sensor data and the expected situation(s) is needed. A time critical enterprise as this concerns human safety. In addition, the detection and treatment of more general fault situations is essential. In collaborative situations, this requires common understanding of information exchange between human operator and robot. The possibility to handle also errors in human – robot interaction is critical. The safety aspect therefore does not only require semantic interoperability but also pragmatic interoperability.

For a fast reconfiguration of the whole production system enabled by modular fixtures, an interoperability layer and cognitive robots, the plug and produce philosophy has to be respected in all components. To do so, new interfaces and approaches to make systems (e.g. the fixtureing system with the robotic system and the control system) ad hoc interoperable in an instant way are required. These interfaces should provide data and energy exchange in combination with the plug and produce capability. To reach that goal a detailed specification analysis of information content, evaluation, and adoption of the relevant standards and models will be sequentially employed to formalise the target domain. Related to this, it is also required to have an understanding of the behaviour of all involved systems.

A knowledge-based enabling automated update based on sensed information needs to be developed. In order to make information from the manufacturing process interoperable, data of interest needs to be defined and methods for corresponding interpretation have to be identified (semantic alignment). In order to optimise acceptance of the developed solution, careful attention will be paid to the design of the data-structures (and their understandability) and the user interfaces for seamless human computer interaction.

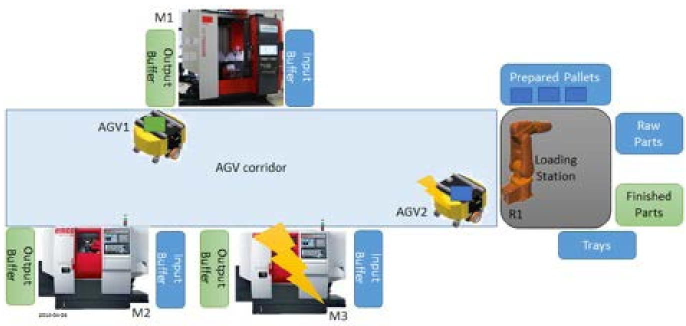
Expected and Achieved Results

Since its earliest days and up to now, production companies are able to compete successfully if they produce faster, cheaper or with better quality. Up to now, the majority of (process) innovations address these aspects separately. This project aims to demonstrate how these goals can be addressed in an integrated manner by means of manufacturing process adaption as well as design modifications. As a side effect, the manufacturing process will be more adaptive. Adaptive scheduling algorithms and automated adjustments of process parameters will be demonstrated. Key functions of adaptive production systems comprising the following aspects will be implemented within a demonstrator representing the major components of a typical shop floor.

Expected results

- adaptive process control: real-time determination of chatter
- predictive QA: the sensing machines - warning functions based on sensor data evaluation
- showcase learning possibilities for reconfiguration of manufacturing resources
- adaptive scheduling based on in-depth production monitoring
- teaching simple tasks to robots using natural interaction
- interactive human - robot message exchange in manual tasks
- job shop schedule optimisation
- tweeting machines – process and condition monitoring by machine-to-machine communication and platform connectivity

The demonstrator for milestone 1 brings together research along these many expected results. It consists of two interrelated use cases that demonstrate the joint integration. On the local-level, a robot solution (Pro²Future) picks unsorted raw parts and sorts them into pallets. These pallets are transported to machines for processing. The demonstrator shows the simple integration of robot human interaction and integration with the CDP centurio Workflow engine. The second use case is situated at the macro-level and focuses on integrating shop jobs with adaptive scheduling (Pro²Future). The novel aspects of the demonstrator include considering transport means as a limited resource and source of failure as well as integrating reliability information into the schedule for obtaining resilience: low impact of failing machines and transport means.



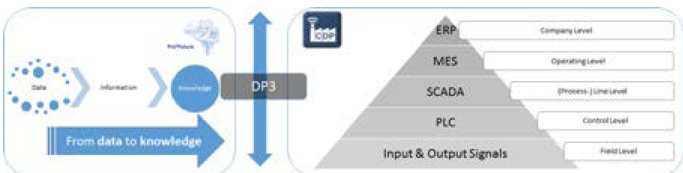
EXECUTIVE SUMMARY

DP 3

Data Analytics for Industrial Process Improvement

Today, manufacturers are more and more able to collect and analyse data from sensors on manufacturing equipment, but also from other types of machinery, such as smart meters, pipelines, delivery trucks, etc. However, many manufacturers are not yet ready to use analytics beyond a tool to track historical performance. However, knowing what happened and why it happened is not sufficient anymore. Manufacturers need to know what happens next and what actions to take in order to get optimal results. It is a challenge to develop advanced analytics techniques including machine learning and predictive algorithms to transform data into relevant information for providing useful insights to take appropriate action. This project targets new analytical methods and tools that make insights not only more understandable but also actionable. The latter requires that the results of data analytics have an immediate effect on the processes of the manufacturer. Thereby, data analytics will improve industrial processes by reducing maintenance costs, avoiding equipment failures and improving business operations.

Accordingly, the **overall objective of this project is to develop a toolset (set of algorithms, analytic machinery and visualizations) for industrial process improvements based on data analytics**. This set of tools will not be bound to any sector of industry and will aim at specified goals, e.g., “prediction of failure”, “improvement of energy consumption”, “remaining number of future usages”, “correction of deviations and drift”. This tool set will be demonstrated within the setting of two smart factories (Vienna and Graz).



Goals

It follows that the ultimate goal of this project is to improve industrial processes by means of data analytics, which will be achieved, by a combination of data-driven knowledge generation and corresponding redesign and reconfiguration of processes. In order to support the decision makers (responsible for changing the processes) it is essential to visualize process designs, running process instances, recognized defects or inefficiencies, and possible changes. Furthermore, it is critical that the decision maker is aware of potential effects of process changes. Thus, this project will deliver a simulation tool to evaluate different alternative shop floor process changes. If a process is changed, the corresponding effects may be local to a specific level of the automation pyramid or it may have cascading effects on other levels of the pyramid that will be supported by this project. In addition, this project will provide a secure data communication protocol which will enable the communication of data to be analysed e.g. between production sites. Eventually, it is the goal to evaluate the framework by a common use case, which is independently demonstrated at two different smart factories (in Vienna and in Graz).

In summary, this project aims towards six main goals: (i) process redesign and reconfigurations by means of data analytics, (ii) visualization of processes and process changes, (iii) simulation of data and process alternatives, (iv) support of cascading process changes, (v) secure data connections, and (vi) use case based evaluation in smart factories.
This joint project aims towards creating new knowledge for improving/adapting already existing processes by use of data analytics and its means of visualization. The simultaneous and systematic examination of data and processes will support production at all levels.

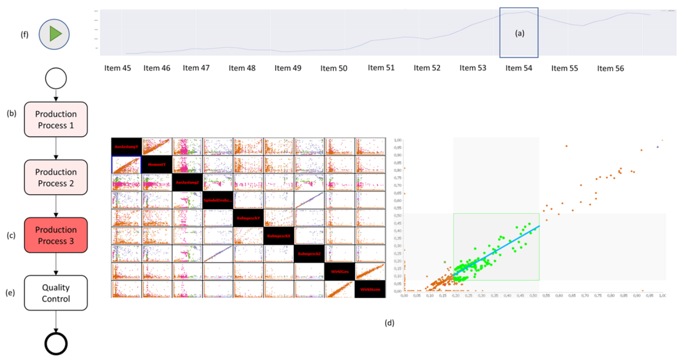
Approach

This project investigates on applying the data analytics concepts (as envisioned by Pro²Future) to the process-oriented view (as envisioned by CDP). Accordingly, the project envisions flexible production processes that benefit from data analytics. In this joined project we will gather and analyse (including visualizing) production data, interpret it in the context of production processes in order to support the decisions on process design and execution as well as for delivering the corresponding process enactment.
CDP follows a process-oriented view in order to facilitate production processes. It is envisioned that the necessary process steps are (semi-automatically) derived from the product design, although manual process design is also supported to give the process owner a complete set of design choices. The P2F approach is to (1) monitor horizontal and

vertical (production) activities and to make the (production) progress visible, (2) develop predictive models based on the collected data, (3) analyse data across automation pyramid levels in order to generate data-based models and knowledge.
In a joint collaboration, this project identifies potential functionalities in improving production processes by means of data analytics. In a subsequent process the conceptual approaches and methodologies to deliver these functionalities are to be developed. These conceptual approaches and methodologies are supported by fully functional research prototypes. These prototypes should be used in case studies that serve both as a proof-of-concept evaluation and as demonstrators that facilitate the technology transfer.
In order to reach these goals, the academic partners have to collaborate with both IT providers and manufacturing companies. The Smart Factories in Graz and Vienna will provide requirements, uses cases and data for different tasks in various work packages. They will support data & process knowledge collection as well as testing for models and evaluation of tools. Evidently, the manufacturing companies serve as demonstration partners in the real-world case studies. The IT providers will not only serve as critical reviewers in the development of the conceptual approaches and methodologies, but also as implementation partners to develop the prototypes.
This project will be implemented in close coordination with the other two DPs. Specifically, DP 2 will provide production data across the automation pyramid (potentially across the secure data connection) to DP 3. In turn, parts of the DP 3 toolset can be applied within the Smart Factories. It is envisaged that data concerning the production process of one specific product will be provided to DP 1. Requirement analysis and use case definition have to be closely aligned with the needs of smart products and production systems.

Expected and Achieved Results

This project delivers a reference architecture, tools and demonstrator for production process analytics, covering the following components:
Integration of data and processes. To gather a fully integrated view on data and processes we define three core tasks: (i) **Data Analytics Aware Processes**, that allows the integration of data analytics as regular steps of a production process that provide relevant context information for production steps, (ii) **Data Driven Process Design Improvement** that analyse production processes in the past in order to improve the production process design, and (iii) **Data-Driven Process Reconfiguration** to provide self-healing capabilities for production processes on basis of live data analysis of production data streams.
Tools for Visual Data Analytics. This component allows the interactive visualization of processes based on process definitions and historic and (near) real-time measurement data obtained from nodes of the processes (i.e., machines in a production line). To this end, a set of tools to appropriately visualize the data at hand will be realised. The toolset will support a process expert to monitor processes in (near) real time and hence support the decision-making process, based on interactive data visualization.



Data & Process Simulation. This component supports cognitive decision making by the simulation of data in production systems. The effects of possible decisions on the various process levels will be shown and can be evaluated by the end-users.

Secure Data Connection Framework for Cross-Level Process Optimization. This component supports cascading effects of changed process designs or process instances at different levels (of the automation pyramid). It consists of a technological infrastructure, which allows for a highly secure transmission of data in a distributed production environment, and respective data integration tools for efficiently handling design changes over multiple process levels.

Smart Factories as a testbed for model verification. A common use case for both Smart Factories is going to be elaborated and defined. According to the common goal of this use case, both locations will capture large amount of data from various sources. On basis of both data silos data analytics will be implemented and evaluated. These tools will find their validation again on the more specific processes at both locations of the Smart Factories.
The final result will be a **two-staged demonstrator** in each Smart Factory. These will provide local small and medium sized companies the opportunity to gather new ideas for their digital transformation and define new projects.

Results Achieved PY1 – PY3: Results in progress PY4
Integration of data and processes: We integrated data analytics into process management by making the data analytics results part of the process logic**.** The **data analytics component** allows analysing data from the production systems and making recommendations for adapting production processes during run-time of the process engine. The **process engine** is responsible for storing and executing the process models and to coordinate the data collection. The component is also able to integrate new insights from the analytics component as well as from the simulation component during runtime. Additionally, the process engine can integrate new insights from the visual analytics component during design time.

Visual Data Analytics: The **visual data analytics component** allows the interactive exploration of big data streams based on a visualisation of the process model. Thus, the deciders are able to conduct a root cause analysis and to identify process improvements quickly during design time.

Data & Process Simulation: The **simulation component** evaluates alternatives of process execution during the runtime and recommends process adaptations.

Secure Data Connection Framework for Cross-Level Process Optimization: The **secure data connection** allows for a highly secure transmission of data to the process engine as well as between all other involved components.

All the components have been developed based on a first set of use cases in the Pilot Factory in Vienna/Aspern.

Smart Factories as a testbed for model verification: Concept for smart production solution for small and medium sized companies has been defined and will be evaluated by the end of 2020.

5

PROJECTS

WORKING TOWARDS PRODUCTS AND PRODUCTION SYSTEMS OF THE FUTURE

Pro^{2}Future

Products and Production Systems of the Future

AREA 1

MFP 1.4-1 SeeIT
Augmented Work Processes

Area 1 - Perception and Aware Systems

Project ID: MFP 1.4-1
Project Title: SeeIT - Augmented Work Processes
Project Lead: Alois Ferscha
JKU, Institute of Pervasive Computing

Duration: 36 Months, 01.01.2018 - 31.12.2020
Strategic Volume: 10 %

Work Packages

WP1: Actuator Technology
WP2: Software Platform Development
WP3: Interaction Modalities
WP4: Integration
WP5: Evaluation
WP6: Project Management

Company Partners

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Harsh industrial environments, where workers interact with machines, tools or other entities (such as robots or other workers) provide a difficult terrain for human computer interaction. It is the aim of SeeIT to provide workers with digital augmentation using different forms of deployment, body worn/mobile or infrastructure based different fidelity of transmitted content, e.g. manuals or video snippets and different sensory targets, such as visual, auditory or tactile channels. The aim is to create a holistic human-in-the-loop system as pluggable interaction component, which can be used by sibling projects, Guide and WorkIT.

Due to the complex needs of industrial reality and the harshness found there, e.g. noise pollution or changing lighting conditions, perception capabilities of workers are limited and need to be considered carefully, especially when critical information needs to be received by a worker. The interaction design is therefore three folded based on general suitability, information flow (unidirectional vs. bidirectional) and content perception. SeeIT considers therefore several factors when providing augmentation: (i) environment factors like noise pollution or changing lightning conditions, (ii) actuator availability such as distance, viewpoint or powered off, (iii) content availability like media available for a specific sense or device, (iv) worker preferences and (v) worker applicability such as sensorial load for a given sense. In addition to that the system will provide the user with a way to interact with the presented information, either implicitly, e.g. by behavior change, or explicitly, by providing input via devices. The major focus will however be on implicit interaction, such as capturing the response of a worker, i.e. in terms of behavior change, to a system triggered information display. We are therefore particular interested in observing overt behavior changes, such as turning the head towards the audio source or avoiding to get closer to a dangerous machine. But we will also investigate intrinsic behavior changes, such as a reduction of cognitive load measured by eye tracking devices or GSR wrist bands. Finally, we aim to use sensory channels which are not already highly engaged, as proposed by Wickens' Multiple Resource Theory. In addition, we strive to not bind a huge amount of attention for long periods of time but aim to make use of subliminal stimuli, such as vibration or ambient lightning, and to provide brief information exchanges, e.g. through video snippets. These three categories, general suitability, information flow, and content perception, will be used to select the best suitable modality in case the system, e.g. Guide or WorkIT wants to exchange information with a worker.

Goals

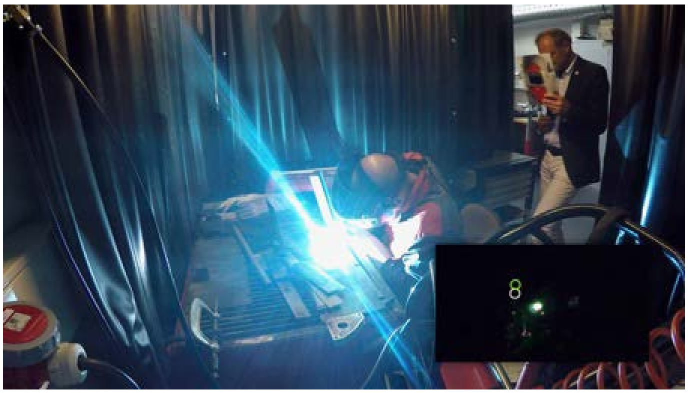
The project goal is to communicate digital information on different modalities (visual, haptic, auditory), whereas the content is prepared independently of a specific device at the information source, e.g. WorkIT' workflow recognition module, but tailored to a specific device at the information sink. E.g. an attention capturing notification, will be sent by the source and will be translated by the system into a specific modality, the best suitable at this point in time, which then at the receiving device node will be translated into e.g. the exact PWM frequency for the vibration motor to raise the attention. The translation processes considers various factors such as environmental limitations, e.g. ambient noise, or worker limitations, e.g. viewpoint towards a screen or prior engagement/load of a sensory channel but also contextual information, such as the current workstep in a workflow.
In addition, the presented information can be acted upon both explicitly by using input devices, such as eye trackers or implicitly by changing or not changing of current behaviour, be it overt -- e.g. body pose -- or intrinsic -- e.g. decrease of cognitive load. The interaction response again will be used to manipulate or stimulate further feedback but also to train the system into learning how successful feedback is given not only on a general basis (i.e. pretrained) but for the system to learn how to provide feedback for a specific user individually.

Approach

The system will be designed based on previous work and make use of a message oriented architecture. Trigged by components of other project, i.e. Guide and WorkIT, rather generic feedback, e.g. alert, will be processed in two stages. The first stage will select the best suitable modality, where several factors are considered: (i) environment factors, (ii) actuator availability, (iii) content availability, (iv) worker preferences and (v) worker applicability such as sensorial load for a given sense. In a second stage the selected modality and content will be transformed on a device node into an actuator specific format, e.g. a vibration message will be converted into the corresponding PWM sequence. The feedback can be interacted with both explicitly with dedicated devices or implicitly by observing overt and intrinsic behaviour (changes). In addition, the system will use the response of the user to learn and self-optimise how to best provide feedback in future interactions.

Expected and Achieved Results

The project should result in a multimodal hardware and corresponding software prototype, which is able to provide feedback using infrastructure and mobile/wearable devices, which are able to stimulate visually, auditory or haptic. We plan to have each output device fully connected via an IP network. A central controller acts as mediator between the information source, e.g. a workflow recognition module, and information sink, an output device node. This controller receives generic feedback mechanism, e.g. alerts, and first derives by sensor data from the network which modality: (i) visual, (ii) auditory or (iii) haptic is best suited based on the following: (i) environment factors like noise pollution or changing lightning conditions, (ii) actuator availability such as distance, viewpoint or powered off, (iii) content availability like media available for a specific sense or device (iv) worker preferences and (v) worker applicability such as sensorial load for a given sense. Secondly, based on the selected sensory modality the now selected content will be send to a dedicated output device node, which may translate or adapt the content for a specific actuator, e.g. a vibration pattern is converted into a pwm sequence.
After the feedback is provided by the system, it waits either for explicit interaction using dedicated devices, such as eye trackers, or observes both overt behaviour, like body pose, and intrinsic behaviour, like cognitive load. Hence, through this machine perception of how feedback is affecting a worker, we aim to close the loop and provide that again as an input for both selection of modality but also about when and how to interact with a user. Therefore, the system will optimise itself to best fit its user. We foresee that, in conjunction with Guide and WorkIT, we will be able to provide work step relevant information such as position in workflow, work step instructions, material and tool parameters, while at the same time decreasing information overload by ensuring that cognitive load is within expected values.



Status/Progress

This project officially started in January 2018. In it, Pro²Future is working with our Company Partners Fronius, KEBA, Wacker Neuson, Trumpf, and the Institute of Technical Informatics Technology at TU Graz towards the creation of the cognitive feedback engine. The project kick off has been held in conjunction with the sibling projects Guide and WorkIT. Afterwards initial inspections took place at each company partner individually to (i) investigate environmental perception limitations, such as ambient noise, (ii) examine already existing actuators present at the resulting workplaces and (iii) available content to be used by workers for their tasks. In parallel, as the project aim is to capture human reaction and perception of feedback, work started into integrating an eye tracker as a rich source of information. Based on eye tracking data we aim to primarily monitor cognitive load as intrinsic behaviour indicator for feedback reception, but also to capture, if feedback has been perceived, e.g. primarily visually but secondly, also auditory or haptic as users tend to focus on information sources.
Furthermore, an investigation was launched into which actuator technologies, both infrastructure or mobile/wearable and which types of modality was already investigated and deployed by other researchers into harsh industrial environments. Based on this survey, promising ready-to-use technologies were integrated as device nodes, such as tablets or wristbands, each of which can be used to provide all types of modalities. The tablet being used as an infrastructure device whereas the wristband as a wearable. In addition to off-the-shelf components, we implemented also an embeddable tactor component, which can be driven by any I2C device such as an NVIDIA Jetson/Xavior or a Raspberry PI. As the tactor is used as subliminal vibration stimulation device, we also wanted to provide a subliminal visual stimulus device, therefore we implemented another embeddable component, which drives either a single RGB LED or a whole group of RGB LEDs. Here, the idea is to use colour-coded feedback in the peripheral vision of a user to trigger behaviour changes or make him aware of something in the environment. The next step will be to create the reinforcement algorithm, which is used for the feedback optimisation mechanism.

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AREA 1

DP1.1-1 WorkIT

Workflow and Tool Process Modelling

Area 1 - Perception and Aware Systems

Project ID:	DP 1.1-1
Project Title:	WorkIT - Workflow and Tool Process Modelling
Project Lead:	Alois Ferscha JKU, Institute of Pervasive Computing
Duration:	39 Months, 01.01.2018 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP1: Workflow and Awareness Modelling

WP2: Framework for Assembly Tasks

WP3: Industrial Workflow and Awareness Analysis

WP4: Use Case Analysis and Prototype Design

WP5: Integration

WP6: Strategic: Supporting Workflow Recognition

WP7: Project Management

Company Partners

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The vision of WorkIT is to establish cognitive capabilities in today's conventional products (e.g. power tools or machines). To achieve this, anything surrounding the worker in an industrial context, be it product, robot or machine, needs to be self-aware and possesses self-organisation capabilities to orchestrate the recognition of workflow and tool processes with others. In addition, the self-organisation approach needs to have the worker in the loop. Overall a collective behaviour of humans and machines needs to be formed, as (i) machines actively adapt to users behaviours and needs by (ii) algorithms and systems which facilitate coordination and collaboration and (iii) exploiting worker and machines strengths (HABA/MABA). WorkIT along with sibling projects SeeIT and Guide is a component of and targets the creation of a general cognitive assistance system.

However, establishing cognitive abilities in product components, tools or machinery requires three levels of awareness: context-, activity- and self-awareness. Specifically for context awareness, we are interested in recognizing the state in the underlying workflow, composed of activities, i.e. work steps, which are performed in sequence or parallel by humans and machines. For activity awareness, we are interested in the recognition of atomic tasks executed by workers, e.g. grab/place a workpiece, which together form a work step. Finally, we are integrating machine/robot states and tool and material parameters, e.g. selected or measured torque in a dynamometric key or detection of metal sheet size, to formulate self-awareness of devices.

The main focus of WorkIT will therefore be centred on recognition of explicit human behaviour, i.e. recognition of the work tasks but also by combing that information with implicit human behaviour, e.g. cognitive load, to formulate an overall cognitive state of an industrial worker. For these recognition tasks, WorkIT will deploy both infrastructure-embedded and mobile-wearable sensors, which either solely or collectively can be used to deduce the worker state. For explicit behaviour recognition, we target to recognize activities, which are of large value in the industrial field of manufacturing, such as screwing in complex assembly tasks or assessing quantitatively quality values of metal working tasks, like welding or metal bending. For implicit behaviour, we aim to leverage existing advances in detection of cognitive state, e.g. using GSR or Pupil Dilation, and aligning them with work tasks to estimate task complexity.
WorkIT's deduced cognitive state of the collective of worker, machines and tools will be used as input for sibling project Guide, e.g. to deduce action plans, or SeeIT, e.g. to provide what the next task is.

Goals

The goal of the project is to provide awareness of three kinds: context-, activity- and self-awareness for cognitive machines and tools or as a pluggable embeddable component, which could even be part of robots or stand-alone. While the second form of awareness, activity awareness, is targeting industrial workers, the last form, self-awareness, is targeting machines or tools, the first form, context-awareness is concerned with underlying processes, i.e. workflows, where men and machine need to cooperate to achieve a particular -- e.g. manufacturing -- goal. Vice versa, in order to understand context, i.e. recognize workflows, one needs to recognize human behaviour, both explicit and implicit, and machine behaviour on a shop floor.
With the industrial setting provided by the company partners, the project will support workflow recognition for assembly processes, metal forming and joining by leveraging information from embedded-infrastructure and wearable-mobile sensing devices. The goal is to combine various information sources making it not only feasible to do workflow recognition but also to provide a high level of reliability by providing redundant, overlapping or disjoint sensor data either of the same or different kind, such as e.g. multiple camera image sensing onto the same viewpoint, depth sensing from multiple angles, or combing data from IMUs and head-worn cameras. Additionally, we aim to recognize task complexity by also incorporating physiological data indicative for the cognitive state.

Approach

The system will be designed around a self-description approach and publish-subscribe principle of sensors and their data. High-level awareness modules, i.e. context-, activity-, and self-awareness, harness this approach by potentially combing data from various sources. We aim to receive data from tools, e.g. welding pistols, machines, e.g. bending machines, and from human-focused dedicated sensors either attached to a worker or embedded in the environment of the shop floor. Based on this self-awareness of machines and tools, and the activity-awareness of dedicated sensor software/hardware modules, we aim to implement a high-level context awareness, in the form of workflow recognition. A particular focus of the project will be to fuse together various data sources into a multi-layered recognition chain for a high level of reliability.

Expected and Achieved Results

The project aims to develop a recognition and awareness architecture, capable of combing and processing multi-sensor data streams from various information sources, such as machines, tools or human behaviour sensing devices, in near real time to correctly and reliable recognize industrial workflows. To his end the project recorded collect multi-modal sensor streams of sensors embedded into products (e.g. welding torch), machines (e.g. bending machine) or the industrial environment (e.g. top down RGB-D cameras), or worn by workers themselves (e.g. eye tracker), which recorded internal states for products or machines, implicit and explicit behaviour, biometric and physiological, but cognitive indicative, data from humans on the shop floor. We implemented various established (e.g. message queues), but also create novel, pre-processing (tree based reactive streams) mechanisms for this huge and frequent volume of data, to deal with redundant, overlapping and disjoined data by either same or different sensor sources. Based on the raw or pre-processed data, we deployed machine learning algorithms to check for the alignment with workflow specifications and report progress or deviations, by a mechanism, which supports correct task execution, provided by sibling projects Guide and SeeIT.
Additionally we still aim to provide knowledge to ensure correct execution of task order, performance and result, but also aim to distinguish between attentional and systematic errors in manual assembly processes by making use of strategic knowledge, which is created on the fly by repeated work task executions and stored for analysis in a workflow database. This database is also what we used to capture data for classification on the shop floors of our industrial partners. Additionally, we already we able to identify bottlenecks by implementing quantitative assessment methods within the production procedure, such as inefficiencies in single work step, erroneous operation of industrial tools and machines.

Status / Progress

This project officially started in January 2018. In it, Pro²Future is working with our Company Partners Fronius, KEBA, Wacker Neuson, Trumpf, and scientific partner Profactor in Steyr towards the creation of the multi-layered multi-sensor recognition architecture. The project kick off has been held in conjunction with the sibling projects Guide and WorkIT. We started with individual inspections on the premises of each company partner to (i) investigate shop floors, workflow and task executions, (ii) examine already existing specifications and documentations of workflows, and (iii) collect typical or frequent error or mistakes which may happen.

At the same time, we established an ontology map for workflow recognition systems to categorize prior work of fellow researchers. Based on that data we selected promising, both wearable and infrastructure-based, sensors to be used for the collection of multi-modal data streams. We already integrated wrist-worn IMUs, i.e. Shimmer, infrastructure depth sensors, i.e. Intel Realsense, i.e. eye trackers, i.e. Pupil Labs Pupil and off the shelf webcams, by providing sensor description and subscribable sensor data streams.
In parallel, we already implemented workflow modelling tools capable of representing arbitrary industrial workflows with parallel or in sequence executions of work tasks.

Further, we already recorded large multi-modal data streams of all industrial partners, which even includes machines data from bending machine and welding unit, at their shop floors. On this data we applied several state-of-the-art feature extraction and selections mechanisms. Whereas the outcome was fed into both an un-supervised and a supervised, machine learning approach and evaluated against each other with the target to detect atomic activities. Although unsupervised ML looked promising in our laboratory studies, it failed to deliver results in the diversity of shop floor experiments. So far, we are able to detect various low-level shop floor activities like different types of screwing (e.g. wrenching, screwdriver), welding direction or various tasks during bending (e.g. measuring, looking for workpiece) or attaching hoses. The detection was not only performed posthumous in our offices but also on the shop floor, where we looked specifically for weaknesses of the classification algorithms, which we are investigating and addressing.

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AREA 1

DP 1.6-1 GUIDE
Guidance and Assistance

Area 1 - Perception and Aware Systems

Project ID:	DP 1.6-1
Project Title:	Guidance and Assistance
Project Lead:	Alois Ferscha JKU, Institute of Pervasive Computing
Duration:	33 Months, 01.04.2018 - 31.12.2020
Strategic Volume:	10 %

Work Packages

WP 1: Models and Knowledge Representation

WP 2: Recognition System and User Classification

WP 3: Guidance and Assistance

WP 4: Use Case and Prototyp Design

WP 5: Integration

WP 6: Strategic: Supporting Worker Guidance

Company Partners

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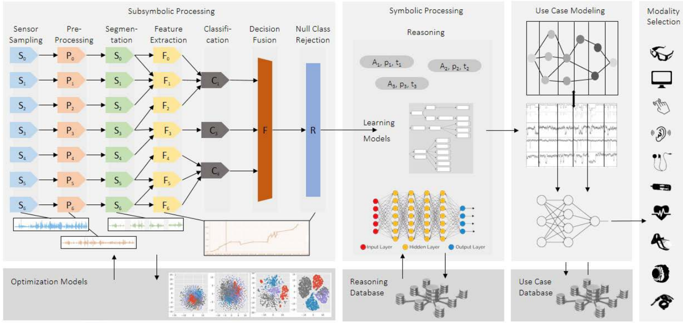
GUIDE will investigate novel worker context recognition, assistance and guidance technologies for use in the manufacturing- and production setting. The project is motivated by the fact that suboptimal outcomes of interactions between man and machine (measured via product quality and manufacturing efficiency) are correlated with (i) the cognitive load and level of attention of the factory worker, (ii) the frequency and degree of disruptions during the manufacturing workflow, as well as (iii) misalignments between the worker's skill and the task complexity. GUIDE will attempt to model the level of cognitive load of human workers in the execution of tasks and is thus related to fundamental research in the interdisciplinary fields of cognitive science, computer science, industrial research, and behaviorism. Further, GUIDE will extend beyond current interactive assistance systems that are mainly restricted to presence detection and collision avoidance by not only recognizing production step, but as well interpreting underlying motivation, level of engagement and goal for optimal activity support and guidance. Finally, GUIDE aims at triggering context-sensitive, multi-modal feedback and instructions, depending on the respective current workflow task, adaptable in sensory channel modality as well as with respect to the workers current skill level and wish for guidance.

Typical industrial work processes involve information from a variety of sources, usually spread out over a multitude of locations. Inexperienced workers are thus often forced to divide their attention between performing the manufacturing tasks and seeking information from different sources – a task that has been shown to adversely affect cognitive load and ultimately result in decreased productivity. As part of DP1, GUIDE will contribute towards the development of a prototype cognitive head gear (HMD) that aims at providing all necessary guidance information directly to the worker at the time of need. Specifically, GUIDE will provision a data preprocessing and machine learning pipeline to be executed on the HMD's mobile processing unit. The key investigators aim to achieve this by utilizing an already previously developed framework for opportunistic, multi-sensor fusion in the domain of embedded activity recognition and optimizing it for the requirements of mobile execution in conjunction with the created HMD. This pipeline will be able to utilize low-level sensor data and transform it into high-level classification results related to (i) industrial workflow steps or the (ii) current cognitive state of the user. The produced HMD along with the context recognition framework will be integrated with state of the art industrial work equipment.

Goals
GUIDE has as its goal the detection and reaction to threats for desirable interaction outcomes, thereby preventing the degradation of product quality and manufacturing efficiency. Specifically, GUIDE will monitor (i) human factors such as the vital state (fatigue, fitness), skill and experience, cognitive load (stress), ongoing social interactions,



distractions and peripheral interrupts (background noise), (ii) workflow complexity and state with respect to activities, processes, timeliness, exception handling, robustness, and quality assurance, (iii) apparatus complexity and worker skill, especially when interacting with complex manufacturing tools, (iv) support human decision making with respect to complex information (machine- or workflow related), unreliable or uncertain situations, and achieving transparency concerning offered assistance, and (v) minimize cognitive load. In that, GUIDE aims at a modular, opportunistic worker state recognition architecture, that makes use of dedicated mobile sensors (eye-trackers, body pose, and hand movements) and actuators (visual, vibro-tactile, auditory), and at the development of feedback trigger mechanisms, able to support, warn and sense workers during manufacturing, assembly and production tasks.

Approach

GUIDE will (i) **build on- and advance over state-of-the-art methods for cognitive load estimation**, (ii) **machine learning and recognition architectures** tailored to industrial machines and workflow processes, (iii) **build on existing opportunistic sensing architectures**, and (iv) **formulate triggers for worker feedback mechanisms**. To this end, GUIDE will derive a measure of cognitive load and human attention and incorporating the same into a user-centric and redesigned version of the context recognition chain, extended by high-level reasoning and recognition architectures. Subsequently, fused decision classes are matched to workflow process models derived from domain-specific expert knowledge, thereby supporting prediction and support.

Expected and Achieved Results

GUIDE aims at the development of a holistic framework to be used in multiple industrial manufacturing and production use cases as agreed upon with our respective industrial partners. This framework will encompass and consist of the following components: (i) a sensor fusion module used to create viable sensor ensembles in an opportunistic manner. This will go beyond the results of the WorkIT project and be integrated with the context recognition chain as implemented by the GUIDE project, (ii) purpose-build models of human attention and cognitive load, each based on existing research from the fields of psychology and cognition. (iii) a modelling methodology for the abstraction of workflow processes, encompassing expert domain knowledge, activity recognition, context recognition and forecasting, (iv) a skill and experience module, able to infer worker skill and to model experience gain, and (v) a feedback trigger module, which will determine the need for feedback and formulate a recommendation for the feedback modality to be used by the SeeIT project. This framework was integrated and exemplified in a head mounted display prototype developed as part of the demonstrator project 1. For demonstration purposes, the produced HMD along with the context recognition framework provides state of the art industrial work equipment to form a stand-alone, visual support- and guidance system, which we deployed e.g. during shop floor studies at company Fronius. In cooperation with sibling project WorkIT project, and sophisticated machine learning pipelines were developed especially for supervised methods, we developed both a classical feature based machine learning pipeline as well as multi layered deep neural networks, based on state-of-the-art paradigms like CNN (e.g. UNet or Inception) and RNNs in form of LSTMs. Further we also investigated the cognitive state of workers by building a gaze analytics pipeline or using data from a wrist-worn GSR unit, which we to this end used to investigate cognitive load during welding or for skill recognition during welding.

Status / Progress

This project officially started in January 2018. In it, Pro²Future is working with our Company Partners Fronius, KEBA, Wacker Neuson, Trumpf, the Institute of Computer Engineering and the Institute of High Frequency Technology at TU Graz towards the creation of Industrial Worker Guide and Assistance systems. We have held the project Kick-Off, and conducted meetings with all Company Partners at their respective locations to gauge the possibilities and most promising approaches on site. Preliminary data investigation was used to define the initial system models for the guidance and assistance architectures. To this day they are extended using data collected in the WorkIT project, and by results with respect to feedback triggers to the SeeIT project.

So far the machine learning software framework created, in conjunction with sibling project WorkIT, features a classical featured based machine learning pipeline as well as a deep neural network based one additionally the overall toolkit also features interfaces and implementation for abstraction of a workers' cognitive state. The trained machine learning models have been trained for each industrial application of our company partners and extends on all steps of the context recognition chain. The developed tools and components still need to be extended for detecting the need for adaptive feedback to industry workers, however so far, they were able to spot task inefficiency, performance variations and return usage information towards product optimization. Further we also implemented a gaze analytics pipeline used for creating features from a mobile eye tracking unit, which are examined for detecting the workers cognitive state, i.e. skill level or cognitive load. So far, we investigated skill level for company partner Trumpf during bending and cognitive load for Fronius during welding. Additionally, in conjunction with the machine learning and multi-sensor fusion pipeline from WorkIT and the feedback system from SeeIT, we already implemented a new guiding interface for novices helping them during metal bending bending. The work will be extended by the key investigators to all the use cases and showcases the cognitive reasoning capacity of GUIDE.

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AREA 1

DP 1.2-1 Fischer4You

Cognitive Skiing Prodcuts

Area 1 - Perception and Aware Systems

Project ID:	DP 1.2-1
Project Title:	Cognitive Skiing Products
Project Lead:	Alois Ferscha JKU, Institute of Pervasive Computing
Duration:	27 Months, 01.01.2019 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP 1: Skier Skill Recognition

WP 2: Device Selection and Data Acquisition

WP 3: Cognitive Product Recommender

WP 4: Dissemination

WP 5: Project Management

Company Partners

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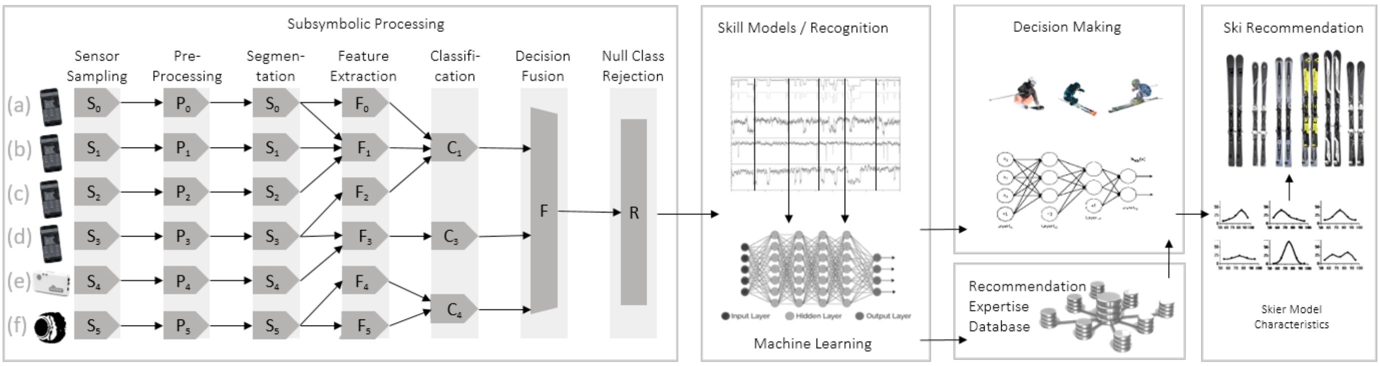
Academic Partners

JKU, Institut für Pervasive Computing
Prof. Alois Ferscha (ferscha@pervasive.jku.at)

Fischer4you will study skier's behavior to find their skill level of skiing, therefore provide them with an appropriate range of equipment and ski skill recommendation. This project is motivated by the fact that every group of skiers need skiing equipment not only based on their general profile but also their technical profile. Fischer4you will try to assess the skill level and performance of skiers in driving different skiing techniques upon a data driven model and therefor is related to fundamental research in the interdisciplinary fields of sport science, computer science, biomechanics and kinesiology. In addition, Fischer4you is not limited to performance analysis, as it goes beyond this by also using the data to recommend users products and suggestion to improve their skills according to their assessment.

Alpine skiing techniques are defined by the Austrian skiing teaching union as the following: Glide, Schuss, Wedging, Snowplough, Drift, Parallel Short Swing, Parallel Long Swing, Carving Long Swing and Carving Short Swing. Each Techniques varies in several regards, like speed or turn rate and they also need to be adapted towards the state of the piste. This makes it hard for unexperienced users to have a consistent behavior in driving different techniques and control speed at each turn. Thus they often lose their control at turns and are not able to manage their speed and body angle to make a good curve, resulting in a lot of severe accidents with other skiers. Moreover, there is a correlation between the behavior at each turn, created curve and its radius, and proper equipment specification. Often users tend to use equipment which doesn't fit their profile or driving style resulting in both a bad experience at skiing as well as endangering others as they cannot fully control their skis. Therefore, Fischer4you aims to get qualitative data insights into the process of skiing using multi sensor setup and also test the feasibility of using just a single sensor smartphone system for broad usage. These insights should deliver where best to place the smartphone to get the best out of the collected data while skiing. In the end the goal is to provision a data preprocessing and machine learning pipeline to be executed on data sent by a smartphone app. This pipeline detect patterns and insights from accelerometer, gyroscope, magnetometer and GPS signals, as well as derived data such as altitude, such as the skier's skill from the generated patterns during skiing, make a skier profile and assist them by a feedback in form of product and ski recommendations and technique guiding.



Goals

Fischer4you goal is to recommend the most suitable ski equipment to each ski driver according to their performance profile and making them aware of their skill level and the level of consistency they have during skiing. Fischer4you will monitor (i) user activities occurring during a skiing day using body worn sensors embedded into everyday smartphones, (ii) user behavior while skiing such as speed control and consistency in driving several different techniques (according to the specification of the Austrian ski teaching union), (ii) user motions such as stability at each turn and acceleration/deceleration after/before each turn, to build a skill assessment model and a skier performance profile. Ultimately, this system, provides users their skiing profile, supports them to access their own driving quality and choose a proper product and to improve their skiing skills. Further the goal is that this system runs on a central server and its assessment can triggered by just using data coming from a mobile phone, which is also used for information users about their skill level and an appropriate product recommendation.

Approach

Fischer4you will build on and advance over state-of-the-start methods for performance and motion analysis, activity identification and skill level recognition relying on machine learning models. Fischer4you will acquire data via IMU sensors and GPS sensors, preprocess the received signals, make a skier profile according to the generated patterns and skiing performance, and derive measures of skill level through a data driven model which compares each user with expert users' behavior, i.e. users which are teaching skiing instructors. Subsequently, skill level fused with the other general information sources, e.g. demographic information, form input to the recommendation system to get both ski product and improvement recommendations.

Expected and Achieved Results

Fischer4you aims to develop a smartphone application to be used by everyone with any level of skill. This recognition pipeline consists of the following components: (i) a sensor fusion module used to create viable sensor ensembles in an opportunistic manner as a basis for motion analysis and activity recognition, (ii) performance analysis and activity recognition models to know what each skier does and how well he is performing each technique, (iii) a data driven model based on expert users profile to be used as a reference for skill assessment (iv) a recommendation module, able to offer the most appropriate equipment to each user, and (v) a feedback trigger module, which will formulate a ski recommendation and potentially also areas of improvements, e.g. like recommending seldomly driving techniques. This framework is to be developed as distributed application, with a sensing and actuating component, e.g. an app on a smartphone, a reasoning component, e.g. implemented as a machine learning server component for recognition, as part of the demonstrator project 1. For demonstration purposes, the produced application on a smartphone along with the skill assessment framework and recommendation system will provide state of the art user assistance to form a stand-alone, visual support- and guidance system for a targeted personas study and for a bigger audience of skiers in the long run.

Status / Progress

This project officially started in January 2019 and will continue till March 2021. In it, Pro²Future is working with our Company Partner Fischer and the Institute of Pervasive Computing at JKU Linz towards the creation of recommendation systems based on skier driving skills. Several projects meeting provided a discussion platform for the overall approach and additionally several data recording session took place not only in winter but also in summer on glaciers. With the current preliminary data investigation is in progress and, in parallel, consortium members have completed the initial system models for the performance analysis, activity recognition and skill assessment architectures. The models have been presented to the consortium partner during the WIP meeting and were discussed in brief, with a more detailed discussion to be held during each individual bilateral partner meeting. Fischer4you by itself will utilize the created models and learning approaches to enhance product recommendation as planned in the project outline. To this end, a machine learning software framework is being created and interfaces set up according to the models and guidelines set forth by the consortium - the focus at this point being the abstraction of skier's skill level based on generated patterns and performance. In the mid-term, machine learning models will be trained for activity recognition, skill assessment and recommendation system. These developed tools and components will determine the need for adaptive feedback to users, increase performance and skill, and return usage information towards a product recommendation. The key investigators aim to achieve this by integrating the developed machine learning pipelines with the multi-sensor fusion framework developed as part of the WorkIT project. In the long term, the devised classification pipeline will be investigated during live studies on snow with a large group of skiers. This is being created right now by splitting several part of the analysis pipeline into dedicated modules, which are either deployed on a central server or the smartphone. Where the former provides the analysis part and the later provides that data gathering and feedback part.

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AREA 1

DP 1.2-3 RTEAS

Cognitive Rail Track Error Analysis Support

Area 1 - Perception and Aware Systems

Project ID: DP 1.2-3
Project Title: Cognitive Rail Track Error Analysis Support
Project Lead: Michael Haslgrübler
Pro2Future GmbH

Duration: 12 Months, 15.11.2019 - 14.11.2020
Strategic Volume: 10 %

Work Packages

WP 1: Domain Knowledge Establishment

WP 2: Statistical Data Analysis

WP 3: Visualization

WP 4: Recommendation System

WP 5: Dissemination

WP 6: Project Management

Company Partners

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Academic Partners

JKU, Institut für Pervasive Computing
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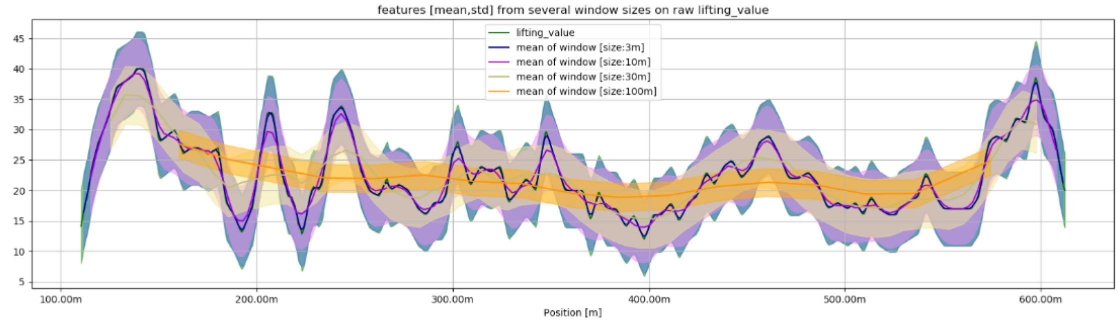
RTEAS will provide support in rail track error analysis based on the data from rail track machines. Along with company partner System7 which builds this kind of machines, the analysis support will be used by System7 customers in the form of reporting and suggestion the maintenance of the rail tracks. E.g. in Europe alone over 200000 kilometers of rail road need to be maintained, whereas a repair job for 500 meters takes several hours. Especially with providing a green alternative to flying, the maintenance of rail tracks is crucial when driving with very high speed, e.g. over 200KM/h. Deterioration of the tracks is not only governed by use but also by bad weather conditions, e.g.strong rain or very low or high temperatures.

Typical rail track maintenance is costly and done with automated inspection of the rail tracks which records errors in several regards, such as longitudinal, directional, or superelevation errors, which can if not mitigated are sources for derailment. These errors occur typically when the underlying ballast bed cannot absorb the force by driving. The errors are fixed using semi-automatic tamping machines, which press together ballast. This process can be repeated on several occasions till a point where the gravel is destroyed by the tamping process and the ballast bed needs to be replaced. In order not to over-tamping areas which don't need tamping as well as finding out when to replace the ballast, RTEAS aims to leverage data coming from the hydraulic units of these machines. Therefore with both historical measurements and maintenance data along with the (i) Rail Road Geometry (Hight shift, direction, Height Variance), (ii) Ballast Measurement (compaction force, Adjustment travel, Regulating time) and the (iii) Position (odometer, GPS, IMU), rail road tracker managers as well as tamping machine operators should get insights into data and also derive action suggestion. Based on a unsupervised machine learning pipeline built in Guide and WorkIT, along with further descriptive data analysis measures, the project team aims to improve the quality of track maintenance and reduce the cost of unnecessary track maintenance.
Additionally, based on the data analysis and the insights gathered from it, RTEAS also will build a reporting engine, which prepares this data into persuasive reports for both tamping machine operators as well as rail road track maintenance managers.



Goals

RTEAS has the goal to to provide decision support for manager and tamping machine operators, suggesting the scheduling of maintenance operations and replacement of ballast bed by monitoring and analyzing the (i) Rail Road Geometry (Hight shift, direction, Height Variance), (ii) Ballast Measurement (compaction force, Adjustment travel, Regulating time) and the (iii) Position (odometer, GPS, IMU). Based on machine learning, e.g. outlier detection, and descriptive statistics, e.g. variance analysis, correlations should be found between errors and data, which guide decisions whether or not to make the correction to the railroads in order prevent failures. RTEAS aims to use the specifically coming from system7 tamping machines sensors, i.e. the hydraulic unit, and will develop the anomaly detection mechanisms able to predict and generate suggestions for further correction in a railroad.

Approach

RTEAS will (i) build on over state-of-art methods for data analysis and correlation in the data for anomaly detections, (ii) Conventional machine learning and recognition architectures tailored to the railroad and temping session data processes, (iii) and powered by an existing data collecting architectures from the system 7 tamping machines. RTEAS will find the correlations, plot, and calculate the wear and tear of the rail track. Subsequently, different anomaly classes are matched to the models derived from domain-specific expert knowledge, thereby supporting prediction, and suggesting the maintenance of the track and guiding decision makers by providing appropriate persuasive reports to either take action in various direction, e.g. not scheduling maintenance for several months or immediate replacement of ballast bed.

Expected and Achieved Results

RTEAS aims at two developments within the project frame: (i) a data analysis pipeline which will be powered by data coming from rail track tamping machines; (ii) a report engine which delivers high quality reports and charts to guide decision makers into appropriate actions. Of course, the main deliverable of this project is the Data analysis pipeline and prediction of the rail track maintenance status. As for this data analysis, we already implemented various expected outputs such as an (i) In-Depth Report on Distribution of Data and Correlation between Problems and Data (ii) Interactive Visualization, which is not yet embedded in System7 Inframe Platform. As for the data analysis company partner System7 expects to find correlation between several relevant data classes, namely geometry data (longitudinal error, directional error and superelevation), ballast bed measurements provided by the hydraulic units (compaction force, compaction path length and time) and position (odometer and GPS data) and to be provided with scientific visualization results clearly indicating underlying problems.
Further in the Recommendation part of the project, the main outputs are (i) the implementation of deriving appropriate actions in reporting Engine (ii) and the preparation of reports on Decision Making by providing necessary visualization and outlining circumstances for actions. Additionally persuasion techniques typically found in HCI sustainability projects should be applied to these reports.

Status / Progress

This project officially started in November 2019 and will end in November 2020. In it, Pro²Future is working with our Company Partners System7, with a delayed kick off held in December 2019 due to organizational incapacities at the company partners side. Various meeting till December 2019 were held for the team to establish the necessary domain knowledge needed for the data analysis. Preliminary data investigation was done in January 2020 and, in parallel, responsible members have completed the initial data analysis approaches and the methodologies which will are now the foundation to build the RTEAS projects. The analysis reports have been presented to the partner during monthly meeting and were discussed in detail. Along with further acquisition of domain knowledge and improvements in System7 data acquisition on their tamping machines work has been done on providing Statistical data analysis and visualizations (Distribution analysis, correlation analysis). By now the machine learning and descriptive statistics pipeline is ready for the anomaly detection and can provide the automatic reports, based on data coming from temping session.

Ongoing work is to stabilize the development of this pipeline regarding data anomaly found in sensor output of the hydraulic units. In the second half of the project the Data analysis framework will be further extended by the engine, which recommends the track maintenance operations and provides persuasive material for the both track maintenance managers and operators alike.

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AREA 1

MFP 1.2-2 3D-RECON
Cognitive Assistance

Area 1 - Perception and Aware Systems

Project ID: MFP 1.2
Project Title: Guidance and Assistance
Project Lead: Michael Haslgrübler
Pro2Future GmbH

Duration: 12 Months, 01.04.2019 - 31.03.2020
Strategic Volume: 10 %

Work Packages

WP 1: Projektspezifikation und Datengenerierung

WP 2: Data driven Multi-View Stereo

WP 3: Data driven Structure-From-Motion

WP 4: Test und Evaluierung

WP 5: Dissemination

WP 6: Projektmanagement

Company Partners

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Academic Partners

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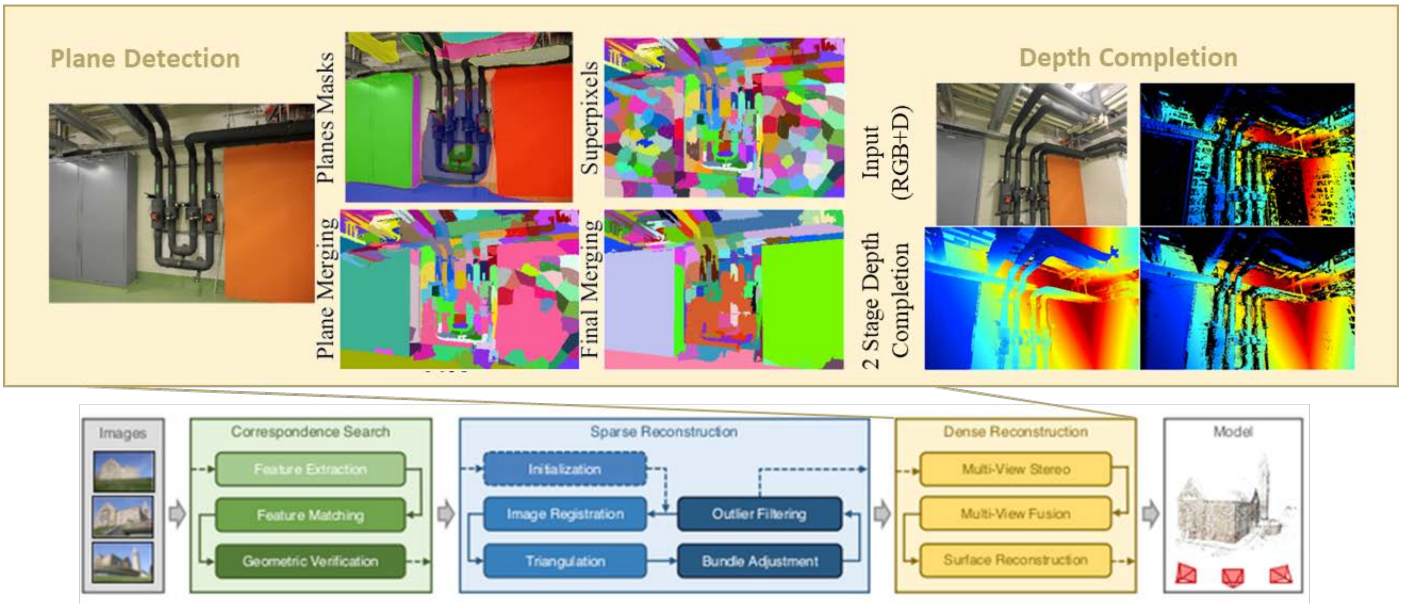
The aim of 3D-Recon is the research and development of methods for high quality 3D reconstruction from images in two dimensions: (i) making use of deep neural networks for higher precision and accuracy on camera positioning and (ii) making use of deep learning and computer vision in 3D reconstruction. In a first step the project will focus only on reconstruction of static scenes, i.e. rooms and not on dynamic scenes which e.g. include moving humans. The fundamental goal of the project is to provide improvement on existing benchmarking data from the scientific community as well as company partner Sony.

The project team believes that Deep Neural Networks (DNNs) have the potential to improve the quality of image-based 3D reconstructions, which could be at a very later stage be used by millions of users equipped with cameras in there smartphones, while e.g. laser based solutions will never be a commodity good.
In order to leverage this benefit, in a first step the project team aims to improve 3D reconstructions, using neural networks on high-resolution image datasets as available by the ETH3D benchmark and using them for geometric image-based 3D reconstruction. With this approach, we foresee that especially in areas where traditional methods fall short, e.g. surfaces like large walls, ceilings or floors a substantial improvement beyond the state of the art can be made.

The improvement will be made in two areas of multi-view stereo (MVS) pipelines, which are like classical two-view stereo methods, which build up a cost volume by matching image patches along the epipolar line. MVS however construct a cost volume by computing costs for a set of given plane hypothesis. The first area of improvement will be confidence prediction which is an inherent part of MVS methods. It calculates costs by local patch comparison based on metrics like e.g. Normalized Cross Correlation. The second area of improvement will be depth refinement, since there MVS methods tends to fall short in untextured areas, e.g. walls, where the matching becomes ambiguous. Here most 3D reconstruction pipelines include a refinement step meant to remove depth outliers or even estimate missing depth areas. Often these methods rely on a confidence map, as it is critical to understand which depth map areas are reliable and which need to be extended.

Overall, we aim to compare our improvements on the multi-view stereo reconstruction methods with existing approaches on scientific benchmarking sets like COLMAP or ACMM.



Goals

3D-Recon has the goal to advance 3D Reconstruction in two dimensions (i) making use of deep neural networks for higher precision and accuracy on camera positioning and (ii) making use of deep learning and computer vision in 3D reconstruction. In a first step the project team aims to improve in these areas, using high-resolution image datasets as available by the ETH3D benchmark and using them for geometric image-based 3D reconstruction. With this approach, we foresee that especially in areas where traditional methods fall short, e.g. surfaces like large walls, ceilings or floors a substantial improvement beyond the state of the art can be made. The project will focus at this stage solely on static scenes where there are no dynamic objects moving in front of the camera. Advancing image-based 3D reconstructions, has the benefit, in comparison to laser-based solutions, that they could be used at a very later stage by millions of users equipped with cameras in their smartphones.

Approach

3D-Recon will build on- and advance over state-of-the-art methods for multi-view stereo pipelines.
The first area of improvement will be confidence prediction which is an inherent part of these pipelines. It calculates costs by local patch comparison based on metrics like e.g. Normalized Cross Correlation. Here we use pixel-wise estimation of the expected noise in the 3D space based on trained data from a neural network. The second area of improvement will be depth Refinement, since there MVS methods tend to fall short in untextured areas, e.g. walls, where the matching becomes ambiguous. Like most 3D reconstruction pipelines we include a refinement step meant to remove depth outliers or even estimate missing depth areas. Here build upon a pretrained plane detection neural network and super pixels to estimate the true planes in a 3D space.

Expected and Achieved Results

We aimed to establish a large improvement on accuracy and precision by estimation the camera position in a structure from motion system, with the ultimate goal to enable improved and comprehensive reconstruction of indoor rooms, with large quantities of low textured planes like walls, ceilings, or floors in contrast to existing state of the art solutions.
This new approach was developed in a software pipeline and applied to various kind of benchmarking datasets of the scientific community and demonstrate the feasibility of image based 3d Reconstruction. The areas of improvement in our multi-view stereo approach are in confidence prediction and depth refinement, two steps which are crucial to 3D reconstruction from images. In both areas we made use of deep neural network to advance our overall method.

This was achieved by confidence prediction networks which have been adapted to the Multi-View Stereo (MVS) case and are trained on automatically generated ground truth established by geometric error propagation. We demonstrated the utility of the confidence predictions for the two above mentioned steps in outlier clustering and filtering and additionally in the depth refinement step, shown in the Figure.

Status / Progress

This project officially started in April 2019 and finished in March 2020. In this project, Pro²Future worked with our Company Partners Sony and the Institute of Computer Vision and Graphics at TU Graz towards the creation of a multi view stereo pipeline useable for 3D Reconstruction from images. Various projects meetings were conducted with company partners either at TU Graz or in Stuttgart. In addition to senior staff, a student researcher Tarek Boamer and junior researcher Christian Sormann were assigned to the project.
Within the frame of the project Tarek Boamer, started and finished his master thesis, named "Machine Learning for Image Based 3D Reconstruction" focusing on depth refinement using plane CNN and superpixels. Together the project team finished the pipeline and evaluated it against benchmark datasets in the scientific community. The evaluation showed an improvement in relation to the start of the art in various scenes from the dataset. The approach and evaluation results was compiled into a paper named "DeepC-MVS: Deep Confidence Prediction for Multi-View Stereo Reconstruction" and is currently under review. Overall the goals of the project were achieved and it was a success for all partners and will continue with a follow up project on the same topic.

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AREA 2

DP 2.1-1 APS.net

Adaptive Production Systems

Area 2 - Cognitive Robotics and Shop Floors

Project ID:	DP 2.1-1
Project Title:	Adaptive Production Systems
Project Lead:	Christoph Mayr-Dorn Pro2Future GmbH
Duration:	39 Months, 01.01.2018 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP 2.7: Interoperability and Consistency

WP 2.10: Showcase Integration

WP 2.11: Project Management

WP 2.12: Strategic Research

Company Partners

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Academic Partners

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PROFACTOR, Flexible Production Systems
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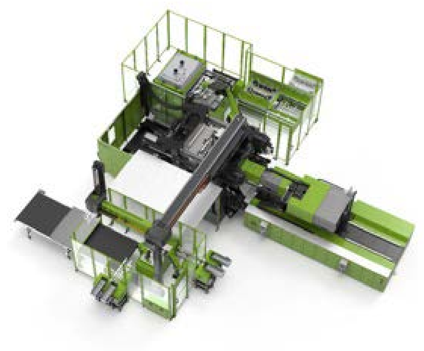
This SFP investigates models, architectures, techniques, and algorithms for increasing the flexibility and adaptability of industrial production systems. Software, and specifically, software architecture plays a central role in achieving these goals. The general capabilities of a production plant depend on its physical layout. Yet, which capabilities are invoked, in which order and under which conditions is controlled mostly by software or human operators. Thus, fast and cheap reconfiguration can only happen through software designed to allow for adaptability and flexibility. In these systems, physical aspects such as material flow, manipulation of physical objects, and physical layout of machines and humans, play a major role.
In this SFP, we borrow concepts, approaches, and ideas from software Architecture to guide the design of Cyber-Physical Production Systems (CPPS). Adaptability in CPPS comes in two main categories: **adaptation of the software** (i.e., machine configuration, process configuration etc.) and **adaptation of the physical layout** (i.e., relocating machine, mobile robots, autonomous guided vehicles). Both categories imply software adaptability.
Traditionally, with little or no product change, engineers custom tailor the software for the machines/robots/production cells specifically for a particular product. With increasing demand for adaptability, two orthogonal adaptation dimensions emerge. On the one hand, we distinguish between the **levels of adaptation**, and on the other hand, we differentiate according to the **locality of adaptation**. The former describes adaptation of product-specific vs machine-specific code, while the latter separates adaptation within a machine, invisible to the outside (local), from adaptations affecting multiple machines (distributed).
APS.net investigates models for achieving interoperability on multiple levels. We aim to achieve this by ensuring
such a model will allow **hierarchical/self-similar modeling** of shop floors down to individual software components within a machine. From the point of view of a single component, interoperability can then occur on the same level as well as with components on lower levels and higher levels, while exposing capabilities, allowing discovery and monitoring regardless of hierarchy.
Such a model allows to define blue prints for (i) which **capabilities** are needed in a production processes, (ii) describe **collaboration** among production cells, machines, robots – hence supporting the cognitive reasoning on a component's surroundings and its role within, (iii) allow reasoning on optimally **distribute control and dataflow**, for (iv) ultimately achieve distributed process execution.



Goals

The overall applied research-centric goal is to **investigate a new middleware** for the shop floor that enables semantic interoperability and flexible adaptation of machines and shop floor configuration. In particular, the focus is on the question of how machines, robots, and increasing demand for adaptability, two orthogonal adaptation dimensions emerge. On the one hand, we distinguish between the levels of adaptation, and on the other hand, we differentiate according to the locality of adaptation. The former describes adaptation technical interoperability through **interface standards**, (ii) achieving semantic interoperability through the use of **data standards**, (iii) support for programmatic interoperability through **infrastructure & central services**, and (iv) support of engineering, development, deployment, operations of modular and adaptive systems. The ultimate goal is having a framework that allows the discovery of production entities, composition of their capabilities, distribution for decentralized execution, monitoring of that execution, and continuous adaptation thereof.

Approach

The approach is based on **"Design Thinking". Stage1 Empathize:** Interviews and workshops with company partners showed the current limits of flexibility of machines and processes at the shop floor. **Stage 2 Definition**: Based on this, specific objectives of flexibilisati on were defined and use cases were developed in which target attainment was to be measured (e.g. relocation of a production process from one production cell to a non-identical one). **Stage 3 Ideate:** Based on a study of the state of the art and research, several architectural solutions have been identified. **Stage 4 Prototype:** Simple/ advanced prototypes focused on the basics and iterative enhanced prototypes allow fast implementation of ideas. A first simulation of flexible machines and OPC-UA was realised. **Stage 5 test:** Scientists and engineers at the industrial partner evaluate the prototype and thereby generate feedback for the previous four stages. The whole process is highly iterative and non-linear; feedback from each stage to previous ones is not only possible but also explicitly desired.

Expected and Achieved Results

This project has two main expected results: **(i) a framework for modeling capability-based production processes**, **and (ii) a framework for distributed/adaptive execution of production processes**. Along the lines of the former expected result, an extensible meta-model provides the basis for modeling actors (humans, machines, robots), processes (work steps including control and data fl ow), parts (the physically input and output of work steps), and resources (such as tools). A key aspect are "**capabilities**" which describe abilities that humans, robots, machines provide **without having a tight coupling** to the providing actor. A first version of such a meta-model is complete. This model serves as the basis for an algorithm to semi-automati cally **match discovered capabilities** (from machines etc.) **to abstract processes** (i.e., based on capabilities only). Model and algorithm are available in an editor. The second main expected results, where preliminary aspects are complete, is an algorithm for **analysing the control and data flow among process steps** to allow optimally allocating not only capabilities but also control logic to actors in a distributed fashion, thus enabling decentralized process execution. The distribution procedure involves directly linking up actors that need close collaboration such as machine-robot synchronized actions, dynamically generating and deploying code, as well as dynamically interpreting and executing subprocesses on machines and robots. Production step distribution and execution is only one aspect. Scheduling multiple process across the same machine is an equally relevant, orthogonal challenge. The expected result is creating a **scheduling algorithm** (based on prior project results) that **considers failing transport mechanisms** (e.g., AGVs) as well as machine failure likelihood to produce resilient plans. Such **resilient plans** may be less optimal in terms of throughput, but require less costly, less impactful, changes in the event of failures, which is especially relevant during ghost shifts.

Status / Progress

APS.net officially started in January 2018. The industrial partners in this project is ENGEL Austria, a manufacturer of high precision, high quality, and high variant injection moulding machines used in domains such as automotive, teletronics, medical, packaging, and many others. The scientific partners include the Institute for Software Systems Engineering (ISSE) at the Johannes Kepler University Linz (JKU), and the Group for Flexible Production Systems at PROFACTOR, Steyr. Given the highly iterative approach based on Design Thinking, regular on-site meetings at ENGEL with weekly conference calls are necessary and welcome to align industry needs and research approach.

The initial task was to collect the technical, organisational and non-functional requirements of the industrial partner and the state of the art. First investigations showed that existing approaches and models insufficiently covered the distributed and modular nature of Cyber Physical Production Systems. The core of a novel model was developed within the strategic project in Area 2, with extensions for shop floor and machine/robot interactions developed within APS.net. An accompanying process editor allows to design abstract processes, discovery of machine capabilities from the shop floor and allocate abstract processes to a discovered setup of machines.

Together with the ISSE a demonstrator, the „Factory in a box“ was developed, consisting of independent plotting stations and conveyor belts. The different systems were structured in a modular way, inspired by the Actor Model of Computation by Hewitt. This leads to a reconfigurable production plant that allows to add, remove and reposition systems without need of reprogramming the individual systems. Each system hosts ist own controller, created in different programming languages, showcasing distributed control and interoperability.

Current work focuses on support and guidance for workers to track error sources in such modular production cells.

Part of this project focused on the joint demonstration with the Austrian Center for Digital Production (CDP) in Vienna. To this end, this project jointly established a demonstrator that exemplifies how, on the one hand, robots, AGVs, and imaging systems can be integrated for ghost shift production, and, on the other hand, how to achieve resilient, adaptive scheduling of jobs.

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AREA 2

MFP 2.5-1 A2PS

Adaptive Assembly Process System

Area 2 - Cognitive Robotics and Shop Floors	
Project ID:	MFP 2.5-1
Project Title:	Engineering Collaborative Machines
Project Lead:	Christoph Mayr-Dorn Pro2Future GmbH
Duration:	19 Months, 01.04.2018 - 30.10.2019
Strategic Volume:	14.5 %

Work Packages

WP 0: Project Management

WP 1: Interoperable and Adaptive Process-oriented Systems

WP 2: Digitalisation and Design Support for Assembly Systems

WP 3: Security & Safety

WP 4: System Evaluation

WP 5: Strategic Research

Company Partners

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PROFACTOR, Flexible Production Systems
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This MFP investigates models, architectures, techniques, and algorithms for increasing the flexibility and adaptability of cyber-physical production systems, specifically here adaptive assembly process systems (A2PS).
A primary concern in assembly production systems is increasing the flexibility and adaptability as companies move towards producing highly customizable products in small lot sizes at the costs of mass production. A2PS exhibits **tight dependencies** between work steps, their duration, input, required machines/tools/skills, product variants, product mix, and production cells/stations. Any **disturbance** such as missing work input, delays, or degraded resources will **cascade and grow**, potentially bringing production to a standstill when left unmitigated. Hence self-adaptation is a key concept to managing such complexity.
The desired **flexibility often limits the applicability for full automation**. On the one hand cognitive capabilities required for adaptation to unforeseen situations can (so far) only be achieved by human operators. On the other hand, programming and configuring all the necessary automation steps for each and every product variant (e.g., gripping positions and movement for robots) takes an excessive amount of time and needs to be updated often. From an economic point of view, human workers are more efficient for such tasks. Self-adaptation approaches in A2PS have to explicitly account for **humans participating in the adaptation loop**: not only as part of the adaptation control logic but also as the entities subject to adaptation.
In assembly lines, workers are learning and optimizing their activities from experience or from their peers. Regularly, mitigation actions become necessary to overcome micro-deviations locally. Experienced workers help out novices (e.g. an expert jumps in where ever s/he notices delays about to happen, workers reorder their tasks while they wait for a late input part to arrive). Such **local optimizations** by human workers are a natural way of **self-adaptation at the lowest, local level**. Such behavior prevents basic deviations to grow but cannot guarantee that deviations won't cascade.
At the same time, these deviations make monitoring more difficult, as even with perfect observations available, these would not match the expected behavior. The **challenge**, hence, becomes obtaining an **accurate picture of the current production** that is robust to the above micro-deviations while remaining able to detect ''serious`` deviations early. Specifically, in this project we address the challenge of obtaining a reliable view on the assembly progress through modeling of prescribed assembly processes, monitoring **heuristics** that are **robust to incomplete observations**, followed by deviation detection algorithms that highlight impact of deviations.

Goals

The overall applied research-centric goal is investigating a novel approach for supporting of networks and flexible shop floors with dedicated focus on assembly processes. Concrete goals focus on **(i) modeling of human-intensive assembly processes** and **(ii) monitoring of human-intensive assembly processes**. The former aspires to obtain a model of the organizational units carrying out the assembly work (i.e., assembly stations and human workers) flexibly integrated with the assembly process steps, assembly part structures, and required tools. The requirement is to **go beyond rigid, control-flow driven processes** as these limit the workers' flexibility to react to unforeseen circumstances. At the same time the goal is to allow constraints among work tasks to allow reasoning upon the assembly progress in the presence of incomplete and deviating observations. A key element in modeling and monitoring assembly work is the **high amount of variability** within the assembly products which needs dedicated modelling support. The later concrete goal addresses the need to establish an accurate view of the assembly line without complete, fine-grained observations.

The industry partner specific goal for Wacker Neuson and Fabasoft are **obtaining a live/continuous picture of the assembly progress**, respectively show case how assembly processes, product orders, and assembly progress can be managed in the cloud.

Approach

The approach is based on **"Design Thinking". Stage1 Empathize:** Interviews and workshops with company partners showed the current complexity of monitoring progress on the assembly floor and involved intra-organizational logistics. **Stage 2 Definition**: Based on this, specific objectives of monitoring were defined and use cases were developed in which target attainment was to be measured (e.g., detecting deviations and notifying logistics department). **Stage 3 Ideate:** Based on a study of the state of the art and research, several architectural solutions have been identified. **Stage 4 Prototype:** Simple / advanced prototypes focused on the basics and iterative enhanced prototypes allow fast implementation of ideas. A first simulation of assembly processes was realized. **Stage 5 test:** Scientists and engineers at the industrial partner evaluate the prototype and thereby generate feedback for the previous 4 stages. The whole process is highly iterative and non-linear, feedback from each stage to previous ones is not only possible but explicitly desired.

Expected and Achieved Results

This project has two main expected results: **(i) a framework for assembly process modeling**, and **(ii) a framework for assembly line monitoring and deviation detection**. Along the lines of the former expected result, an **extensible meta-model** provides the basis for modeling actors (humans, stations, assembly line layout), processes (work steps and dependencies among steps), parts (the physically input of an assembly step), and resources (such as tools). A key aspect is modeling dependencies of assembly steps that are specific to a particular product feature. A first model version including cloud-based editor has been achieved. The second main expected result consists of an assembly-floor sensor integration with a cloud-based assembly tracking tool, heuristics that are able to **infer from incomplete and indirect (privacy-respecting) data** to the overall assembly progress (within specified boundaries), a **deviation detection mechanism**, and algorithm for inferring the **impact of deviations** in one part of the assembly process onto upcoming assembly steps as well as on subsequent process instances. A set of heuristics have been implemented that apply constraints among work steps and stations to infer additional progress information. Detecting deviations in a timely manner is of uttermost importance. One potential application of the deviation analysis and impact estimation is notifying logistic about (upcoming) changes such as delays or steps reordering. This allows to deliver **the right parts at the right time to the right station even in the presence of assembly deviations**. The deviation analysis can also serve as input for supporting the redesign of the assembly line by highlighting which products in their particular feature configuration and assembly production sequence were prone to deviations, thus identifying loci of improvement, ultimately making the production sequence more **resilient to deviations**. To attain this goal, a weekly/daily assembly dashboard has been implemented in the Fabasoft cloud updating the progress of stations and processes in a near-real-time manner and summarizing the detected deviations in different categories.

Status / Progress

A2PS officially started in April 2018. The industrial partners in this project are Wacker Neuson, a manufacturer of high-customizable construction machines such as digger, dumpers, excavators, and compaction devices, and Fabasoft, a provider of cloud services for the digital control of documents, electronic assets, processes and record management. The scientific partners include the Institute for Software Systems Engineering at the Johannes Kepler University Linz (JKU), and the Group for Flexible Production Systems at PROFACTOR, Steyr. Given the highly iterative approach based on Design Thinking, regular on-site meetings at Wacker Neuson and Fabasoft with two-weekly conference calls are necessary and welcome to align industry needs and research approach.

We started by defining an Assembly Process Model (based on the core model devised as part of strategic research in Area 2) that allows to link stations and worker (roles) to process steps, parts, and tools. Specific care was given to the ability to represent within an assembly process description all possible variants of a particular product (i.e., the 150% bill of process). Constraints amongst steps are also modeled representing the assembly work dependencies. We show-cased how the real assembly processes at Wacker Neuson can be modeled using APM, and highlighted details and relations not yet captured by the existing IT infrastructure. We further prototyped the management and visualization of process specifications and process instances in the document-centric Fabasoft cloud.

The next steps included capturing observations on the assembly floor. Manual observations of several product instances with varying features provided timestamps for part picking and work step execution activities as a baseline dataset to test monitoring heuristics against as well as to obtain insights which and how many observations are required for a particular level of progress accuracy, respectively, timeliness. This analysis also informs the decisions where to place sensors and what their sensing frequency needs to be. A set of monitoring heuristics were defined for the tracking of assembly steps progress. We then applied these heuristics to obtain an accurate process view of the assembly floor. Subsequently, comparing the actual work status with the prescribed one allowed us to determine the expected impact such as how delays may cascade down several stations, or what mitigation actions can be set to mitigate the impact, respectively get the assembly work back in 'tact'. Different types of deviations are detectable with our approach including (i) steps executed in longer time than expected, (ii) stations exceeding the allocated tact time and (iii) altered assembly sequences. The approach requires merely standard sensory infrastructure on the assembly floor such as weight-sensitive part boxes or pick-by-light systems. Shopfloor progress information and deviation analysis is provided back in near real-time via a cloud-based dashboard solution hosted by Fabasoft.

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AREA 2

MFP 2.5-2 LineTACT

Cognitive Line Tacting Support

Area 2 - Cognitive Robotics and Shop Floors

Project ID:	MFP 2.5-2
Project Title:	Cognitive Line Tacting Support
Project Lead:	Christoph Mayr-Dorn Pro2Future GmbH
Duration:	24 Months, 01.03.2020 - 28.02.2022
Strategic Volume:	10 %

Work Packages

WP 0: Projekt Management
WP 1: Takterstellungsprozess - Kontextanalyse
WP 2: Analyse bestehender Modelle, Ansätze & Verarbeitungsalgor.
WP 3: Alg. & Services für Abhängigkeitserstellung, Ableitung, und Verfeinerung
WP 4: Algorithmen und Services für Line Tacting
WP 5: Prototypen Architektur und Implementierung (Klick-dummy)
WP 6: Prototype Evaluation
WP 7: Strategic Research Dissemination

Company Partners

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Academic Partners

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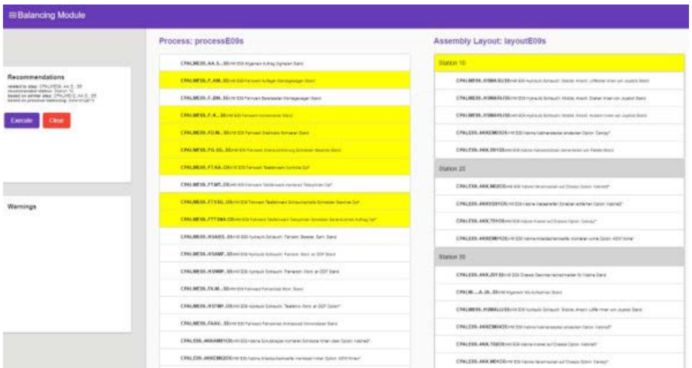
This MFP investigates models, architectures, techniques, and algorithms for reducing the time to rebalance a manual assembly line. A primary concern in assembly production systems is increasing the flexibility and adaptability as companies move towards producing highly customizable products in small lot sizes at the costs of mass production. Manual assembly processes exhibit **tight dependencies** between work steps, their duration, input, required machines/tools/skills, product variants, product mix, and production cells/stations.
Optimally balancing the assembly steps across the available assembly stations requires a **multi-objective optimization**: ensuring that all workers have equally much to do, don't sit idle within a assembly tact, but also are not constantly stressed to meet the tact time, have all parts nearby to avoid non-productive activities such as fetching parts from their (temporary) storage location, achieving this for every station (so that all station consist of roughly equally long work steps, a necessity for a fixed tact), and achieve this over all products on a line as well as all product variants. The result of balancing is a set of assembly processes, one for each product that describes exactly which step is done at which station by which worker using which parts.

One aspect in generating such a distribution of tasks is the **dependencies amongst task** (some task might need another task done earlier such as mounting the tracks requires the prior mounting of the wheels). Hence obtaining a usable assembly process upon introducing a new product or new variant **requires several rounds of design and feedback** from the line before all errors (e.g., impossible task sequences, suboptimal task sequences) are removed. Most often the knowledge to do this is available only as **tacit knowledge among the assembly workers**, station leaders, and line leaders. **Explicitly modelling** all dependencies is not only a **very costly** (because time consuming) task but also **quickly outdated** as smaller and larger adjustments are made in the product design or line layout. Constantly checking and improving the dependencies quickly becomes infeasible.

Instead, this project aims at **reusing data from past** processes, line layout, and parts to find similar situations, extract dependencies from this and produce a baseline line balance. This **reduces the effort required for engineers** to come up with a first balance while having the advantage that the approach and algorithm learns over time from an increasing data set and also encourages thus the exchange of tacit knowledge across production sites. **The challenge** is to derive at suitable similarity algorithms that can distinguish between generally valid dependencies and variant or product specific peculiarities that might not be found in past data. The approach thus has to provide **accurate results even in the presence of incomplete and inconsistent data** (e.g., dependencies in one product are not found in another, and vice versa).



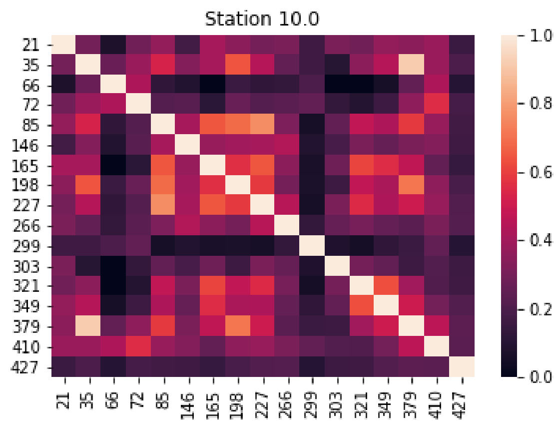
Goals
The overall project goal is - in the sense of applied research – the investigation of a new approach to support the planning of the timing of an assembly line. The primary approach **to reduce the effort for deriving a configuration** is to automate it as much as possible, to generate it at least partially automatically, and thus to have provided a usable basis for manual refinement and expansion.
The specific goal is to **continuously improve the priority graph** (the graph that defines assembly dependencies) without aiming for a perfect graph. Creating a perfect graph is too lengthy and time-consuming and potentially changes again and again. Instead, it should be possible to continuously improve it and to **model how precise / inaccurate certain dependencies** are, hence introducing the concept of the partial fuzzy priority graph.

Approach
The approach is based on **"Design Thinking". Stage1 Empathize:** Interviews and workshops with company partners showed the current complexity of modeling the assembly process and the balancing procedure. **Stage 2 Definition**: Based on this, specific objectives of reducing the time for balancing were defined and use cases were developed in which target attainment was to be measured (e.g., amount of automatically, correctly allocated steps to stations). **Stage 3 Ideate:** Based on a study of the state of the art and research, several architectural solutions and allocation strategies have been identified. **Stage 4 Prototype:** Simple / advanced prototypes focused on the basics and iterative enhanced prototypes allow fast implementation of ideas. A first step similarity measurement algorithm was implemented. **Stage 5 test:** Scientists and engineers at the industrial partner will evaluate the prototype and thereby generate feedback for the previous 4 stages. The whole process is highly iterative and non-linear, feedback from each stage to previous ones is not only possible but explicitly desired.

Expected and Achieved Results
This project has two main expected results: (i) a set of similarity metrics and step-to-station allocation algorithms building on top as well as (ii) a prototype integrating these metrics and algorithms to evaluate the performance of the algorithms and, more importantly, enable the reduction of the time needed for line balancing.
The prototype will be fed with previous line balancing configurations, line layout, list of current steps to be balanced (i.e., allocated across the stations), and each step's involved part (where applicable). The line balancing engineer then has the option to request **step to station allocations** at various levels of accuracy, **obtain rationale why a particular allocation** has occurred, may refine the allocation, and while doing so, will **receive warnings if the new allocation appears to violate** some implicitly learned step dependency. The engineer can always choose to ignore the warnings.
The step similarity metrics help to identify where previously unseen steps (e.g., new steps of a new product) may best be allocated to and what other steps need to come before and may follow thereafter.

Status / Progress
This project officially started in March 2020. Alongside with our partners Wacker Neuson and DMTM, Pro²Future is working towards the cognitive support for assembly line balancing based on step similarity metrics and prior balancing data. We started investigating different similarity metrics to determine the most similar assembly activity based on previous balancing solutions. Then a prototype was developed integrating different functionalities for assembly balancing support. Previous balancing solutions, assembly layouts and the assembly process to be balanced serve as input for the prototype. An upfront automatic balancing will automatically allocate the maximum number of assembly steps to stations based on similarity measures and prior balancing solutions available. Further step-by-step assistance is also possible. The user can request station recommendations or related steps recommendations for individual assembly steps. Alerts are displayed if an allocation violates the drawn assembly constraints. These alerts can then be acknowledged or dismissed. Balancing experts at our industry partner Wacker Neuson evaluated the functionalities of the prototype useful for the balancing process.

The manual assembly processes involve common categories of activities that are repeated in multiple steps and stations. These activities are not very informative of the steps and can affect the similarity measures. We therefore accorded different weights to assembly activities based on their usage within a step or a station. Activities that are not common and are detected in a specific type of steps are very informative and therefore accorded a higher weight value. This helps identify more similar steps based on the core activities of each step. We are further investigating ways to make the balancing process more efficient as a large number of similarity calculations need to be executed depending on the number of steps and the number of available previous balancing solutions. We do not need to compute the similarity of every pair of steps. We only need to locate the most similar step amongst those that are more likely to be similar. In the long term, additional resources (such as tools or parts) can be used as inputs for the similarity measures.



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AREA 2

StratP 2.4-1 HOP-ON

Cognitive Shopfloor Monitoring

Area 2 - Cognitive Robotics and Shop Floors	
Project ID:	StratP 2.4-1
Project Title:	Adaptability and Interoperability of Complex Adaptive Systems
Project Lead:	Christoph Mayr-Dorn Pro2Future GmbH
Duration:	12 Months, 01.04.2020 - 31.03.2021
Strategic Volume:	100 %

Work Packages

WP 0: Projektmanagement
WP 1: Monitoring - Kontextanalyse
WP 2: Analyse von bestehenden Modellen, Ansätzen und Algorithmen
WP 3: Infrastruktur und Services für Kommunikationsmonitoring
WP 4: Prototype Implementation and Evaluation
WP 5: Research Dissemination

Academic Partners

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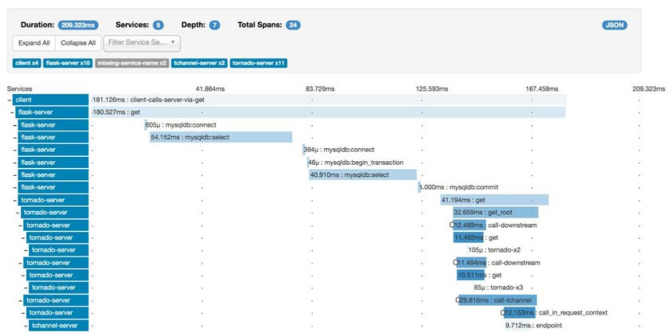
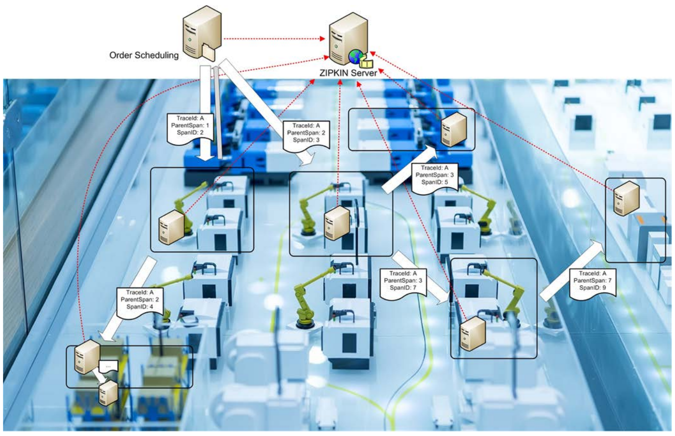
Production Systems are systems-of-systems and very specific and unique systems. Here Production Systems address machines composed of mechatronic systems and also shop floors that are composed out of machines. In order to control, adapt, and achieve interoperability among machines, a common communication infrastructure is envisioned that targets the peculiarities of shop-floors and robotics. Dynamics in the production environments require the system elements (machines, sensors, etc) to be adapted to changing needs. However, this flexibility of adapting a system based on changing behaviour and / or structure of systems that form the system under consideration comes not for free, but needs to be designed in order to be available and hence needs a middleware that support such adaptivity.

The basis of any such adaptativity is awareness what is going on the shopfloor and how interactions among shopfloor participants can be traced back to particular orders, respectively, products.

Goals

The overall project goal is - in the sense of applied strategic research - to enable a new approach to support the monitoring of work processes, orders, implementation on the shop floor / assembly floor between machines, robots, and humans. Approaches from applied software engineering to systems of systems monitoring are to be researched. These approaches are primarily evaluated in laboratory environments, but it is also possible / planned to prototype them with industrial partners (up to Technology Readiness Level 4). This exploration is carried out using software prototypes.





Approach

The project's approach is based on "Design Thinking".

- Stage1 Empathize: Insights into the problems of existing Pro2Future partners and other industrial companies in the context of existing collaboration describe the current challenges and processes in monitoring system-of-systems in the industrial sector. These insights help to make realistic assumptions in the algorithms and prototypes.
- Stage 2 Definition: Building on this, the goals of system-of-system monitoring are adjusted based on new knowledge (stage 1) and use cases are refined, which allow the achievement of the goals of the project to be measured more precisely. Feedback from stage 5 (test) enables iterative adjustments and objectives of the ideal phase (e.g., which model / information sources, i.e. algorithms, were promising, which were not and in which direction the next idea (state 3) and prototype phase (stage 4) should go.
- Stage 3 Ideate: Based on the study of the state of the art and research, existing fuzzy information description models and information merging algorithms are identified for their applicability, expandability, modifiability or their shortcomings.
- Stage 4 Prototype: Simple / iterative improved prototypes focused on the basic concepts allow quick implementation of the ideas. The prototype implementation is based on the prevailing conditions on the shop floors of the industrial partners. Prototypes range from demonstration of individual algorithms, to scenario walkthroughs on paper, to manual simulation of production situations, and use in laboratory environments.
- Stage 5 Test: Scientists (and indirectly reviewers as part of submission reviews) evaluate the respective prototype and thereby generate feedback for the previous 4 stages.

The chosen technical approach basically consists of the following components:

- Enrich communication channels / messages / events / calls with context information: this is planned to be based on X-B3 http headers and Zipkin tracing infrastructure, whereby the header formats are adapted to the respective transport / communication technologies: ie OPC UA header, MQTT message meta information, Akka Actor Message meta information, etc.
- Pass through context information such as order id, iteration ids, batch ids, process step ids, etc. through the individual systems: this means that any reaction to signals (messages, calls, parameter read / writes) can be assigned to a very specific order and can be precisely tracked in what condition and, consequently, why the individual shop floor participants reacted to this order.

Expected and Achieved Results

This project is of high strategic relevance: Accurate monitoring what goes on on the shopfloor and enabling all shopfloor participant to better perceive their usage context is fundamental to adaptation at across all levels. Hence this project investigated following key aspects:

- Tracking processes / orders / activities through a complex production environment (system-of-system) requires the observation of control / data flow, correlation of events / messages across system boundaries and the merging of model information about the individual systems. Due to the different processing speeds (near-realtime machine control, slower human workers) and participants (machine, robot, humans, logistics), this is a significant problem that has not yet been adequately solved.
- A new approach is control / data flow, the correlation of events / messages is not tracked top-down (e.g. in MES) but bottom-up, directly via the effective individual communications, control and data connections.
- As a side effect, the participants were able to experience their work context directly instead of being provided incompletely and with a delay from "above" (i.e., the MES).

Concretely, the expected output of this project are prototypes and accompanying methodology how to incorporate cross shop floor tracing information in communication channels and how to set correlation and sub interactions appropriately.

Status / Progress

This project started 1 April 2020, thus only a few results are available. The first steps focused on analyzing the extensibility and entry point of OPC UA frameworks for integration of tracing headers. In this respect, we have identified ZIPKIN X-B3 headers (as applied in web-based systems) as a suitable mechanism to convey correlation information between machines. We have then identified in the Eclipse Milo Framework the classes, methods, and datastructure in the OPC UA client and server stack where such information can be passed in and out.

The figure below displays the conceptual flow of trace correlation information among shopfloor participants. The trace information is passed on between every participant, even between subsystem within a cell or even a single machine. Upon receiving a reply, respectively completion feedback in the scope of Machine-2-Machine communication, participants send trace information such as start and end to the Zipkin server.

Future steps focus now on the instrumentation of running OPC UA clients and servers in an industrial setting, using the Factory in a Box demonstrator (a collaboration with JKU) as a first proof-of-concept implementation playgroud. This first proof-of-concept will show how trace identifies can be transmitted across OPCUA enabled machines and how the captured trace information can be made available for shopfloor monitoring. The figure below (taken from a web based system) describes how such a monitoring interface will look like. Instead of web services and server instances, the various entries will represent machines and their subcomponents (including logistics and robotic equipment) that are responsible for processing a shopfloor order. One can thus quickly obtain insights into which processing steps where able to be completed in parallel, which steps have taken long, where has been time spent for synchonization or waiting for resources to become available.

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AREA 3

MFP 3.1-1 EPCOS 1

Maintenance 4.0 @EPCOS OHG, Preparation & Ex-Post Analysis

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.1-1
Project Title:	Maintenance 4.0 @EPCOS TDK
Project Lead:	Stefan Thalmann Pro2Future GmbH
Duration:	12 Months, 01.07.2017 - 30.06.2018
Strategic Volume:	0 %

Work Packages

WP 1: Automatic Suggestion of Troubleshooting

WP 2: Ex-Post Analysis

Company Partners

EPCOS TDK
Dr. Michael Prohammer (michael.prohammer@epcos.com)

Academic Partners

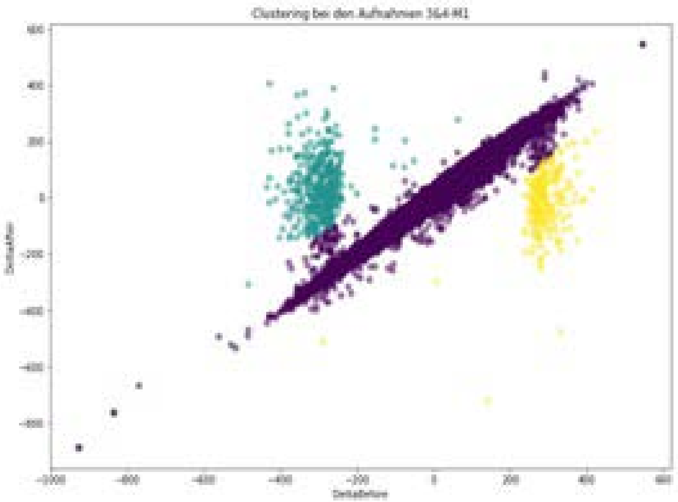
TU Graz, Institute of Interactive Systems and Data Science
Prof.in Stefanie Lindstaedt (slind@know-center.at)

The predictive maintenance systems are built upon is a clear definition of defects and the corresponding approaches to address them. First, the different types of defects should be identified and ranked considering to what extend they may affect the system. The next step is about defining possible methods and strategies that can be used to deal with these defects. Basically, the outcomes of these methods are (i) **predictions** about which kind of error may appear, and (ii) **recommendations** about how to deal with them.

Approach

In order to classify the defects, we defined analyzed two important features, **DeltaBefore** and **DeltaAfter**. This features where identified using visualization approaches like scatterplot, boxplot, etc. and through the discussion with the domain experts from EPCOS. Finally, we structured and processed the data so that they could be readily interpreted from various clustering methods.

We performed different clustering methods (e.g., K-means clustering, GaussianMixture, etc.) over the data. The results showed that the GaussianMixture performed better as it could cluster the defective parts successfully (see Figure below). The green and the yellow clusters represents the defects, and the purple cluster represents the normal behaviors.



Much effort has been put on collecting high quality event data (EASTGATE data). Analyzing this information together with the Log data and ISPRO data, we were able to deploy a classification model based on Random Forest.

Expected and Achieved Results

The goal of the defined model was to classify the defects in advance. Therefore, we defined various prediction horizon (e.g., 2, 5, 19, 20 and 60 minutes), which represented the prediction time before the defects happened. Next, we defined various time ranges (windows) (e.g., 10, 20, 30 minutes) each representing a period in which we observed the data to generate predictions. The following table shows the results.

		Vorhersagehorizont				
Analysewindow/Minutes – **10 minutes**		2 Min	5 Min	10 Min	20 Min	60 Min
	Accuracy	0.74	0.83	0.81	0.77	0.82

Status / Progress

This project officially started in May 2018 and successfully ended in September 2018. In it, Pro²Future worked with our Company Partners EPCOS, TU Graz Institute of Interactive Systems and Data Science towards the creation of models to classify defects on produced chips. From the start of the project, we had several meetings with the company partner where we defined the requirements, discussed the data quality and presented the preliminary results for the classification models. During these meetings, we obtained constructive feedback which we could use to adapt the models with regard to the requirements of the company partner. The final prototype has been delivered to the partner on the 28th of September 2018.

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AREA 3

MFP 3.1-2 DEFCLAS
Advanced Defect Classification

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.1-2
Project Title:	DEFCLAS Advanced Defect Classification
Project Lead:	Stefan Thalmann Pro2Future GmbH
Duration:	07 Months, 01.11.2017 - 31.05.2018
Strategic Volume:	10 %

Work Packages

WP 1: Classification of Defects

WP 2: Best Practice Guideline

WP 3: Literature and Conceptual Framework

WP 4: Project Management

WP 5: Preparation of Training Data and Performance Improvement

Company Partners

EPCOS TDK
Dr. Michael Prohammer (michael.prohammer@epcos.com)

Academic Partners

TU Graz, Institute of Interactive Systems and Data Science
Prof.^{in} Stefanie Lindstaedt (slind@know-center.at)

Automatic optical inspection (AOI) in the semiconductor industry is considered an extremely important and demanding task for detecting significant errors on the wafer fab process within the Quality Process Control pipeline. During this step, yield deviations can more seamlessly identified and engage the engineers to locate the exact source of error with the numerous complex process steps. With the advent of advanced analytic techniques (e.g. Deep Learning) as well as parallel computing (deployment of GPU servers) is now possible to classify and label with a probabilistic manner the errors on the chip surface by feeding large images datasets to Neural Networks. Building such solutions within the QPC of the wafer fab can very demanding and with high degree of complexity.

Goals

The goal of the project is to define models that should help to identify and classify the errors which might occur while producing chips. The outcome of the project should be a best-practice guide on what to consider when defining such models. This mainly comprises the methods that have been successfully applied to address the challenges we faced during this project: export and postprocessing the data from the plant, processing of the trainings data, defining of the classification model for error detection on the chip surface etc. With this guide we aim to support the experts who might face the same challenges in future projects.

Approach

The first challenge is to identify the relevant part of the images. A too large picture can distract and thus reduce the quality of the classification. Further, larger images increase the complexity of the data processing and the performance of the approach. Too small images on the other hand could hide relevant structures and thus reduce the classification quality as well. Chip Images which are used for training a classification model should first contain the appropriate context in terms of defect structure. This means characteristics should be as distinguishable and intense as possible from the remaining complex chip architecture so not to raise any confusion to the later prediction process. As it's possible from the automated inspection system (AOI) to extract the images with the defect centered, that can facilitate for building a more reliable and accurate model.

Expected and Achieved Results

In cases where entire chip images are provided with the four soldering joints (Lötstellen) an initial classifier model (CascadeClassifier) is trained so to extract automatically the areas of interest, namely the four soldering positions. A separate classification model (Haar Cascade Classifier) was first trained on 100 images. Inside these instances, the four soldering regions were manually defined by defining rectangles, enclosing the joints, of certain width-to-height ratio (256x256px) with their location coordinates. The extracted images of the soldering joints are fused with the labelling information regarding the fact that is defect or not.

All defect images should have a constant size which need to be fed into the neural network model initially for training. After interviews and first wafer data we concluded to an image size of 90x90 px so that to achieve a trade-off between algorithm performance (final model size) and classification accuracy. Experiments have been conducted for the initial classification problem of the 3 defect classes ("Druckstelle", "Verschmutzung", "PR-Fehler") so to benchmark the utilized image size (see following figure). Images with sizes greater than 90px (e.g. 128x128) were also tested and findings showed that complexity was increased and thus classification performance decreased.
Convolutional Neural Networks (CNN) with its many architectural variations can fit very well for demanding applications of image recognition tasks. Across the internet there many available datasets (see CIFAR-10 and CIFAR-100 [1], MNIST [2] or also ILSVRC 201* [3, 4]) which are mainly used for benchmarking novel models as well as to mark overall dataset specifications.

We conducted an experiment to examine the effect of the training data size on the classification accuracy. We have deployed the model with the five defect classes from the WB-AOI, as images from within these classes are more homogeneous and stable. It is essential that testing images to evaluate are coming from the same distribution (similar image context within classes), otherwise the outcome will be biased. Also, this is a strong indication that the model should be updated by training it with the novel images, that the model failed to classify correctly. The graph below shows that above 1200 images per class the classification accuracy is converging and thus providing sufficient evidence for the adequacy of the training data size.

Status / Progress

This project officially started in August 2017 and successfully ended in September 2018. In it, Pro²Future worked with our Company Partners EPCOS, TU Graz Institute of Interactive Systems and Data Science towards the creation of models to classify defects on produced chips. From the start of the project, we had several meetings with the company partner where we defined the requirements, discussed the data quality and presented the preliminary results for the classification models. During these meetings, we obtained constructive feedback which we could use to adapt the models with regard to the requirements of the company partner. The final prototype has been delivered to the partner on the 28th of September 2018.

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AREA 3

MFP 3.1-3 OnDaA

Online Data Analytics @ voestalpine

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.1-3 OnDaA
Project Title:	Online Data Analytics @ voestalpine
Project Lead:	Heimo Gursch Know-Center
Duration:	24 Months, 01.10.2017 - 30.09.2019
Strategic Volume:	20 %

Work Packages

WP 1: Data Analysis and Identification of Correlations in Use Case Bramme

WP 2: Building Prediction Model for the Use Case Bramme

WP 3: Visual Analytics Tools for Monitoring Tasks for the Use Case Bramme

WP 4: Prediction Model for Anode Change

WP 6: Strategic: Data Analytics Methods Base

Company Partners

voestalpine Stahl GmbH
Dr. Markus Brummayer, MSc

Academic Partners

JKU Linz, Institute of Computer Graphics
Prof. Marc Streit (marc.streit@jku.at)

TU Graz, Institute for Interactive Systems and Data Science
Prof.[in] Stefanie Lindstaedt (slind@know-center.at)

Know-Center GmbH,
Research Center for Data-Driven Business & Big Data Analytics
Heimo Gursch (hgursch@know-center.at)

This project focuses on data analytics and visualisation for the continuous casting process in large-scale steel production. In modern steel production, sensor and process data are recorded to observe and control the continuous casting process and the resulting product quality. Monitoring this data directly is cumbersome yet demanding for process engineers. Hence, the monitoring is labour intensive, often only done on sample basis or to investigate particular events observed in the finished product, the so-called slabs. To improve the monitoring the sensor and process data, the data is processed by machine learning algorithms. The objective is to create a prototype for a monitoring solution highlighting the right information about the current steel production to the process engineers and limit unneeded or distracting aspects to a minimum.

As a preparatory work, a comprehensive data analysis was required highlighting characteristics of the data and establishing coherences with the steel production process. In the next step, a detailed feature engineering was conducted, where relevant features were derived from the process and data understanding. These features capture the important insights hidden in the raw data and abstract from shortcomings of the raw data like noise. The extracted features are the basis for the machine learning algorithms trained and applied on them. These algorithms recognise and categorise phenomena about the produced steel in the prepared features. Hence, the algorithms provide an estimation about the expected product quality and about the state of affairs in the ongoing process. An important part of the project is the visualisation of the data and the results, so that the process engineers get an ideal overview about the current production state and got informed about potential critical developments. The visualisation is the necessary tool to handle large amount of data in a comprehensible manner by providing different views with varying levels of detail. Hence, the process engineers can choose from different views depending on their task; high-level views to monitor the ongoing processes were also available alongside detailed views to drill down and investigate particular events.

Goals

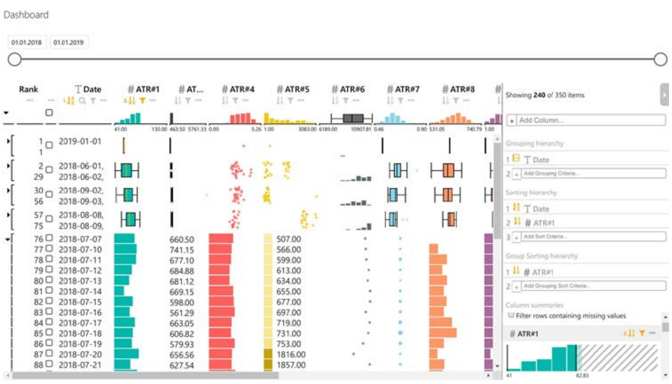
The objective of the project was to conduct research into feature extraction, machine learning and visualisation applications for sensor and process monitoring in continuous casting. The feature extraction defines quantifiable and reliable characteristics of the raw data by modelling aspects of the continuous casting process influencing the output quality. The extracted features needed to be reproducible and robust against noise or variations in the process. The machine learning builds on said features to categorise relevant casting phenomenon in the slabs. This categorised phenomenon helps the process engineers to identify potential issues in the produced slabs and the underlying production process. The visualisation provides these extracted insights in a neat and user-friendly graphical interface to the process engineers. The interface offers different levels of detail giving each process engineer the right amount of information for a given task. On the one hand, a high level of abstraction caters for fast and easy to comprehend overviews. On the other hand, the user process engineer can select high levels of detail if this is required for a detailed investigation of a particular issue.

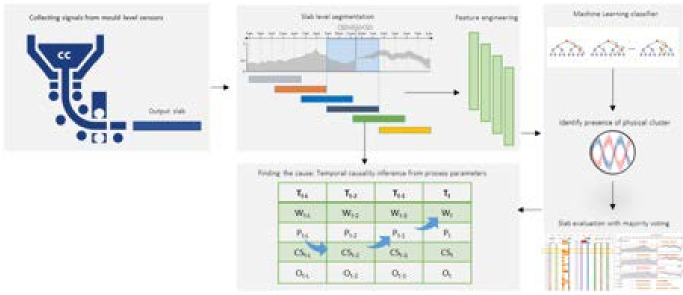
Approach

The centre of the project are machine-learning models. The models are trained to detect relevant characteristics of the produced slabs. In this training and on the subsequent usage of the model, the model relies on features extracted for the raw data. The construction of these features was most important for the success of the project since they capture all relevant aspects in the data, are low in dimension and also robust against noise and variations. While these features are the key success factor for the machine learning, the visualisation was clearly focused on human understanding. The data is presented in a way that is comprehensible for the engineers and shows them the important aspects they need to judge the current products. Hence, the focus is the underlying sensor and process data.

Expected and Achieved Results

In this work, the feature extraction for bivariate time series was investigated. The construction and definition of the features is designed to the specific physical phenomena described by the customer and observed in the sensor and process data of the steel production. The features are the basis for the identification of critical physical phenomena by means of machine learning. The machine learning is conducted in two stages. In the first stage, a multiclass approach was taken to determine if a single dominating phenomenon can be identified for a produced slab. In the second stage, a multi-label approach was chosen to allow the identification of more than one relevant phenomenon occurring in a single slab. The expected outcome was a list of identified phenomena and their influence on each slab. Regarding the visualisation, a visual analytics application prototype was developed. This prototype allows for a general overview and also a detailed drill-down of the underlying time series data. This is facilitated by a customisable ranking including grouping and aggregation of the underlying data. Moreover, a Microsoft Power BI custom visual was developed to explore rankings of items based on a set of heterogeneous attributes. It also supports hierarchical sorting and interactive (nested) grouping as well as provides a variety of visualisations for group aggregations, cells, and summaries of the underlying data.





Status / Progress

This project officially started in October 2017 and went on for 24 months until September 2019. A cost-neutral elongation until the end of 2019 took place to finalise the visual analytics part. The project was conducted with voestalpine AG as industrial partner, JKU Linz and TU Graz as scientific partners, and the Know-Center as implementation partner. The first phase in the project was dominated by a strong knowledge exchange between the partners. In this phase the continuous casting process with its properties and features had to be understood by all project partners.
This understanding was created by a walkthrough of the production plant and several data exchanges. The exchanged data was also the foundation of the remainder of the project. In the second phase, this data was analysed and the coherences and correlations between process phenomena and the data were identified. In this phase of the project, additional data transfers took place when shortcomings in the first data were found or new interesting insights needing deeper investigations discovered.
This phase then led to the feature engineering, where the insights and phenomena, which should be extracted, were defined. All these phases before were the basis for the current implementation and evaluation of the machine learning and visualisation prototypes. The prototypes were evaluated and enhanced in several iterations. In each iteration the prototypes were verified and enhanced. A particularly close cooperation with the industry partner was found in the coordination of the dashboards to find outliers and patterns over time in data by means of three use cases.

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AREA 3

MFP 3.1-4 RedUsa

Predictive Maintenance for Production Environments RedUsa

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.1-4
Project Title:	Predictive Maintenance for Production Environments
Project Lead:	Belgin Mutlu Pro2Future GmbH
Duration:	36+3 Months, 01.01.2018 - 31.12.2021
Strategic Volume:	15 %

Work Packages

WP 1: Data- and Infrastructure Preparation

WP 2: Data Analytics for Quality Improvements

WP 3: Advanced Visual Analytics for Quality Improvements

WP 4: Concept for Introducing/Establishing Data Analytics

WP 5: "Strategic Project" - Data Analytics Methods Base

Company Partners

Austria Metall GmbH
Dr. Manuela Schreyer (manuela.schreyer@amag.at)

Academic Partners

TU Graz, Institute of Interactive Systems and Data Science
Prof.in Stefanie Lindstaedt (slind@know-center.at)

TU Graz, Institute of Computer Graphics and Knowledge Visualisation
Prof. Tobias Schreck (tobias.schreck@cgv.tugraz.at)

The power of the predictive maintenance lies on providing immediate assistance in situations where human judgment disregards the reactions times or when human beings do not possess the required skills. This is considered as highly important particularly in uncertain conditions where making a poor selection might cause high consequences for the production process. This MFP will investigate methods and tools to identify factors that might affects the quality of production and in turn to allow maintenance to be planned before the failure occurs. This project is motivated by the fact that while producing aluminum plates in Austria Metall GmbH (AMAG) and in the affiliated companies (with regard to § 189 a UGB), there might be not-metallic indications in the produced items caused by unknown factors. To be appropriate, these indications have an enormous effect on the quality of the produced plate. In order to tackle this issue, this project should provide methods that can be used to identify the influencing factors and to reveal relationships among these parameters and production quality. Furthermore, the gained insights should be applied to forecast the production. Finally, a visual analytics tool should be provided, which shows the end user (engineers from AMAG CAST) the influencing parameters visually and allows to interact with them.

The data being used in this project are production and quality data.

Goals

The goal of this project is to define visual methods, which can reveal the relationships among production parameters and the production quality. Sensors at various production steps deliver a stream of production data, which is time-dependent and typically, high-dimensional. While the data is continuously captured, its preprocessing and analysis are a challenge, due to the size and heterogeneity of data. The main challenge, however, is to map the time-dependent production data to the run length of the cast aluminum. An interactive visualization tool should therefore provide means to visually inspect the possible influences of production parameters on product quality and promote a better understanding of parameters in production. On the top of that, the tool should be defined in a way that it can be used by the users (engineers from AMAG CAST) that have little or no expert knowledge in visualizations but possess the required domain knowledge about production aluminum plates.

Even with an interactive visual analysis tool that offers users several functions for exploring their data, the users can still be overwhelmed by the huge amount of data and may have difficulties to identify critical patterns in their data sets. With our visual analysis tool, we also want to provide various methods for the detection of specific ultrasonic patterns and thus try to help users to identify possible critical process deviations in production.

Approach

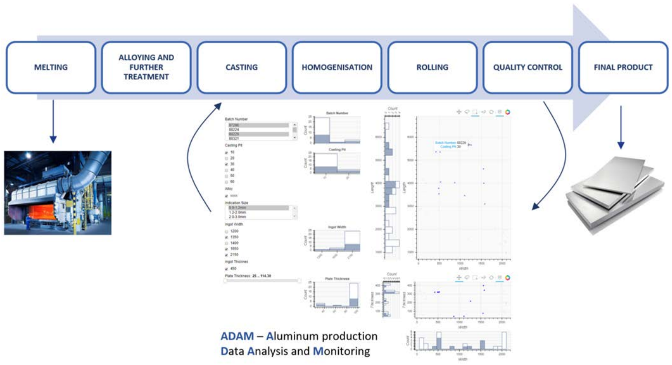
There exist several state-of the art algorithms that can be used to analyse data and identify the influencing process parameter. This, however, requires an extensive literature review to analyse which methods better applies to industrial data. Thus, within the scope of this project, we will investigate different algorithms to detect the factors that might influence the produced aluminum plate and to forecast the production. Note that the data we used within the scope of this project is collected by an ultrasonic device, used to scan the produced aluminum plates. For the visual analytics tool, however, there exist powerful visualization libraries that provide different interactive 2D visualizations. These visualizations provide a good base to support user to visually navigate through the data and explore them to gain insights and draw important conclusions.

Our next goa in this project concerns the identification of meaningful patterns in process data. The existing research covers a broad spectrum of pattern recognition methodologies that can be potentially applied to elicit patterns in data collected from industrial production. Hence, in this paper, we further analyse the applicability of different methods for recognition of specific ultrasonic patterns which may indicate critical process deviations in aluminum production.

Expected and Achieved Results

During a parallel aluminum cast, each batch results in several ingots via a casting pit. We developed a visual analytics tool (ADAM: Aluminum production Data Analysis and Monitoring) which includes scatter plots, showing the front and the top view of ingots, linked with three frequency histograms which provide information about the number of indications in length, width, and thickness of cast ingot. ADAM has been successfully presented at the poster session in EuroVis2019.

Further effort in this project has been put to define a classification model to classify the ingots into “good” and “bad” quality regarding the not-metallic indications they have. Moreover, we defined a prototype of a glyph-based visualization to scale multidimensional data and methods (currently, the classification model) to reveal the relationships among production parameters and the production quality. Yet, batches and ingots have a different distribution of indications in length, width, and thickness. It is important to group similar batches and ingots in order to investigate the influence of production parameters in a more precise manner. To do this, we integrated interactive pattern search in our tool and allowed the user to search for ingots with similar distribution compared to a selected ingot.



Status / Progress

This project officially started in April 2018. In it, Pro²Future is working with our Company Partners AMAG, TU Graz Institute of Computer Graphics and Knowledge Visualisation, and TU Graz Institute of Interactive Systems and Data Science towards the creation of visual- and data analytics tool for quality improvements in aluminum production. We have already deployed an advanced version of ADAM, including the interactive exploration of indications and the pattern search. In near future, we will focus on visualizing the extracted relevant production parameters and on defining methods that should help the users to understand the difference between them with regarding to the quality criteria.

The first results of this project including the interactive exploration of indications and the pattern search have been submitted to the 54th Hawaii International Conference on System Sciences, which should take place in 2021.

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AREA 3

MFP 3.1-5 SINPRO

Predictive Maintenance for Production Environments SINPRO

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.1-5
Project Title:	Predictive Maintenance for Production Environments
Project Lead:	Belgin Mutlu Pro2Future GmbH
Duration:	27 Months, 01.04.2018 – 30.06.2020
Strategic Volume:	15 %

Work Packages

WP 1: Project Management & Coordination

WP 2: Prediction Model

WP 3: Advanced Visual Analytics for Quality Improvements

WP 4: Knowledge Modelling & Integration

WP 5: Strategic Project – Data Analytics Methods Base

Company Partners

Primetals Technologies Austria GmbH
DI Dr.[in] Petra Krahwinkler (petra.krahwinkler@primetals.com)

Academic Partners

JKU Linz, Institute for Application Oriented Knowledge Processing
Prof. Josef Küng (josef.kueng@jku.at)

JKU Linz, Institute for Computer Graphics
Prof. Marc Streit (marc.streit@jku.at)

TU Graz, Institute of Interactive Systems and Data Science
Prof.[in] Stefanie Lindstaedt (lindstaedt@tugraz.at)

This multi firm project (MFP) will investigate a novel decision support technology for assistance in the manufacturing- and production setting for plants in the context of the sintering process. The motivation is, that the outcome in product quality and the manufacturing efficiency can be increased by understanding the circumstances of all components and optimizing their interacting.

Within SINPRO, a huge amount of sensor data is gathered from a sinter production machine and analyzed to understand, which components of the production process affect the quality of the final product. With these findings a prediction model should be defined that uses the detected influencing factors of the whole process and predicts the quality and amount of production. On the top of that, the existing rules of the rule based expert system are investigated to understand current system-changing events and the resulting rules. With these findings, existing rules will be adapted and optimized, and new rules defined to gain a higher production and quality increase on the sinter production machine. Finally, the influencing factors, the prediction model and possible rules, as well as the production data, will be visualized to make the research outcome better understandable for the user.

The pursued results and targeted impact contain findings about the process and relationships in the sinter plant and the sinter process; a better representation of parameters in the sinter plant and the implementation of further analysis in an interactive way, forecasts and predictions for process variables and quality characteristics and a customized expert system and advanced decision support.

The novelty value and scientific relevance embrace the application of data analytics and visual analytics approaches in the area of a sinter plant in the steel industry; new scientific findings and contributions in the field of visual interactive prediction in the industrial sector; requirements and solution models for introducing data analytics in an industrial context; findings about the possible uses or the connection between data analytics and visual analytics; insights into the interplay and connection of data and rule-based decision support in the industrial environment.

Goals

The overall goal in this project is to optimize the production process of sinter material. This should be achieved by increasing the amount of the produced material from the sinter strand as well as improving the quality of the produced material. One of the most important factors to reach this goal is the optimization of the burn through point (BTP) of the material, which should be as close as possible to the end of the sinter strand.

Use Case 1: Understanding the influencing parameters for optimizing the harmonic diameter (DH).
Use Case 2: Optimizing the BTP towards the end of the sinter strand.

By applying the research methods described below, the implementation of the Use Cases should lead to fulfil the project goals.

Approach

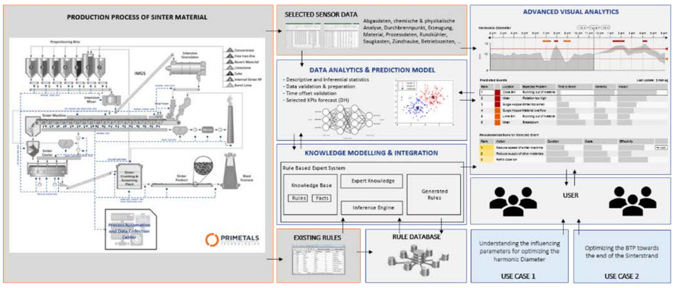
The approach is to understand which factors affect the quality of the final sinter product. With these findings, the project goal should be achieved. The research methods and topics of interest of the approach contain a time series analysis and classification of existing data on production and quality; an identification of influencing variables for the identified classes; the creation of a prediction model for defined parameters; visual preparation of the data from the sinter plant; an user-specific representation of the visualizations; implementing interaction concepts for visual analysis of the data; an extension of the rule-based expert system with findings from the data analysis.

Expected and Achieved Results

The overall goal in this project is to optimize the production process of sinter material. This should be achieved by increasing the amount of the produced material from the sinter strand as well as improving the quality of the produced material. One of the most important factors to reach this goal is the optimization of the burn through point (BTP) of the material, which should be as close as possible to the end of the sinter strand.
We first defined a time model to have reference points for the analysis tools. We further used this model with the feature engineering and selection methods to identify the most relevant parameters for the production. These features are then applied to define a forecasting model to predict the harmonic diameter as a central quality parameter indicating the grain sizes distribution of the finished sinter. Due to the complexity of the model we developed and presented an approach for the increase of the explainability of the complex (black-box) forecasting model, enabling easier discovery of new insights and control strategies.

To visually assess temporal data and the relation between attributes inclusive the related correlation coefficient, we made use of two open-source visual analytics applications and extended their functionality. First, we took advantage of Ordino, an interactive rank-based web application, which is used for data-driven approaches to create, visualize, and explore rankings of items. Second, we added further functionality by using TourDino to calculate and visualize similarity measures. TourDino helped us in seeking relationships and patterns in data and provided an overview of the statistical significance of various attribute comparisons without losing the existing ranking.

Further effort has been put in defining a concept to extend the rule-based expert system. This concept dictates three steps:
(i) development of a prototype for a strand speed control; the purpose of this control is to keep the actual BTP around the BTP setpoint in an acceptable range and the speed as stable as possible
(ii) integration of the prediction models provided by WP 2 into the expert system
(iii) (optional) communication with WP3 for visualization: visually display intrinsic factors which have direct relationships to each other and are related to the strand speed control, and thus to the sinter productivity



The results we obtained so far have been submitted to AISTECH2020.

Status / Progress

The SINPRO project officially started in April 2019 and will last until June 2020. Due to several revisions of the sinter machine, the start was postponed to October 2018, a prolonging of the project end to December 2020 has been negotiated.

The SINPRO team at Pro2Future GmbH is working with our Company Partner Primetals Technologies and the Scientific Partners from the Institute for Application Oriented Knowledge Processing (JKU-FAW), the Institute for Computer Graphics (JKU-CG) and the Institute of Institute of Interactive Systems and Data Science (TUG-ISDS). The associated partners can be found on the first page of this document. The responsibilities within the SINPRO are split according to the work packages and for each WP, one person is responsible: Matej Vukovic (WP2), Vaishali Dhanoa (WP3) and Van Quoc Phuong Huynh (WP4), and Belgin Mutlu for the whole project management.

The Kick-Off Meeting was in October 2018 and several tele-conferences and two workshops regarding important parts of the project, e.g. for the currently installed expert system from Primetals Technologies and the data exchange for the dataset from the sinter machine at Voestalpine Stahl have been hold since then. There were additional meetings for getting in touch with the provided data, getting explanations and gaining an extensive understanding of what is happening at the sinter machine. The first investigations and research resulted in a schematic description of the whole project, showing the individual components and the two use cases of the projects (see Figure below). As next, we analyzed different methods to identify influencing factors and define a prediction model to predict DH. These methods should help us to address main Use Case. Hand in hand with this goal, an interactive visual analytics tool has been defined to increase the explainability of obtained results/models and of the current production data. Finally, we worked on adapting the rule-based knowledge processing expert system with new rules to allow higher production and quality increase on the sinter production machine.

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AREA 3

MFP 3.2-1 GuFeSc
Predictive Maintenance for Products

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.2-1
Project Title:	Predictive Maintenance for Products
Project Lead:	Heimo Gursch Know-Center
Duration:	39 Months, 01.01.2018 - 31.03.2021
Strategic Volume:	20 %

Work Packages

WP 1: Requirements Analysis and Concept

WP 2: Ex-Post Prototype

WP 3: Single Machine Predictive Prototype

WP 4: Scaling Predictive Maintenance

WP 5: Strategic: Supporting Cognitive Decision Making

Company Partners

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Nowadays, customers require more and more specialised products adapted to their specific needs and circumstances. This results in a large number of product variants and options, creating a considerable challenge in the maintenance and support of all these products. Since customers also expect a high quality of support for all products, personnel working in testing, maintenance, repair or customer support require considerable time to familiarise themselves with all variants and available options so that they can satisfy these expectations. This is as cost intensive for the manufacturer as it is cumbersome for the worker. Hence, there is a large potential for assistance systems that provide help to the maintenance and testing personnel and reduce their required training effort. This project researches support systems for maintenance and testing personnel, which are based on data collected during the testing and operation of the devices. One major aspect is to split up the devices into their components. This spilt-up is then the basis to identify relationships between the collected data and the affected components. Since there are many product variants and options, it cannot be expected to have a sufficiently large data basis for all products. Hence, the approaches researched here should be capable of transferring insights discovered in one particular setup to other setups if the circumstances deem this reasonable. This is an important aspect to support maintenance and repair personnel in handling rare problems and setups just as profound as the most common once. The prediction of wearout in some parts is another important aspect of the project. By modelling and estimating the expected wearout of parts, their lifetime can be estimated allowing to schedule required maintenance actions well in advance.

Goals

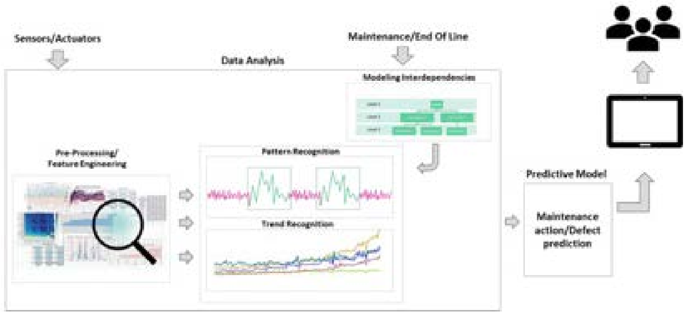
A large number of product variants and options make maintenance and support tasks a complex undertaking where the unique characteristics of the product at hand need to considered. It also implies that there are only a small number of commonalities between different product variants and options. The objective of this project is to research new support systems for workers in fault identification and maintenance. The support system should draw its knowledge from different data sources capturing aspects like successful or failed product tests, product usage data or maintenance action reports. All available data sources currently collecting knowledge for other primary uses should be investigated about their potential applicability for the envisioned maintenance and repair support systems. Due to the large number of product variants and options it is unlikely that for each and every product configuration enough data are available to create a dedicated model. Instead, it is an objective to research the possibility of applying a model and its insights also to other, similar products. In this process commonalities between the different products should be identified allowing conclusions by analogy between the products and use them to derive support for maintenance workers dealing with unseen product variants. This is a requirement to adapt to new products or variants with small lot sizes. Hence, maintenance workers can be assisted with the required information about expected causes for equipment failure, provided with information about what spare parts are most likely required and when maintenance actions should be scheduled in advance.

Approach

This project follows a fully data-driven approach where at the beginning of the project the available data sources of the industrial partner are evaluated according to their potential use in this project. In an explorative data analysis phase, the data sources are matched to the information needed to solve the posed questions. This matching shows the potentials and shortcomings in the available data sources highlighting where additional work or knowledge bases are required. In the next step, the data are used to generate models by using machine learning approaches. These models are crucial for the approach, since they will be used to derive the support actions suggested to the workers from the data describing the case at hand. The models cannot be derived from a single data source but additionally require an interaction with workers to incorporate their knowledge.

Expected and Achieved Results

The project aims at the creation of predictive models to support maintenance workers by suggesting (1) components potentially responsible for failures, and (2) scheduling and type of maintenance actions. These models are derived in a data driven manner from currently available data sources and also knowledge captured by employees on a daily basis. To do this, the data and knowledge are analysed and transformed to train models by means of machine learning. In this process, potential missing information is identified leading to a plan on how to improve and adapt the data collection in the future. Based on the collected data and the already existing product structure, the devices are split into components. Different error pattern observed in the past are then matched to the components, therefore creating the basis to suggest error causes and affected components for maintenance work. This is accompanied by a wearout prediction to estimate the life time of selected parts. Hence, the wearout prediction is essential to schedule necessary maintenance actions in advance.



Status / Progress

The project started with an intensive knowledge transfer between the partners involved in the project. Site visits and workshops provided an ideal platform to exchange knowledge about the conditions in manufacturing and maintenance. This knowledge is necessary to understand and interpret the data sources. The data in these sources were predominantly collected for other purposes, hence, they had to be transformed and re-evaluated for the current task at hand. This was done in two steps; firstly, by the means of exploratory data analyses, including correlation analysis, event and trend identification. Secondly, the interpretation and validation of the results regarding their applicability for the project's objectives. An important preparation for the modelling is the component split of the investigated products and devices. The component split is the lowest level of granularity on which repair actions can be based on. This means, that in case of a necessary repair, the maintenance personnel might get the suggestion to check or replace one or multiple components. Moreover, we build models to predict a future failure of a device. For that purpose, we merged data from a final test system (end of line test) with service data and information about the countries where the devices have been shipped. The predictions results show that the interaction between country codes/average temperature of countries and final test system data leads to statistically significant predictions which can be used in an assistance tool.
When switching from repair to maintenance actions, the prediction of component wearout is currently investigated. However, since a large part of the data are not annotated, we work on methods to automatically annotate maintenance data, so that we can then build and train models to predict the wearout of components.

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AREA 3

MFP 3.2-2 ConMon

Scalable Condition Monitoring System for Test Environments

Area 3 - Cognitive Decision Support Systems

Project ID: MFP 3.2-2
Project Title: Predictive Maintenance for Products
Project Lead: Belgin Mutlu
Pro2Future GmbH

Duration: 36 Months, 01.01.2018 - 31.12.2020
Strategic Volume: 20 %

Work Packages

WP 1: Live Data Collector Prototype

WP 2: Model for Forecasting

WP 3: Visual Analytics Prototype

WP 4: Evaluation and Improvement

WP 5: “Strategic Project” - Data Analytics Methods Base

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The modern industry machines are endowed with multiple sensors producing huge amount of data. This also applies for automotive engine testbed where the durability of an engine is tested applying numerous sensors. The biggest challenge thereby is to collect and extract valuable knowledge from this data. This task becomes even more complex since the data being generated by the sensors are multivariate time series. To be appropriate, to gain valuable insights from this data, one must possess expert knowledge in data analysis of time series data, as well as domain knowledge in automotive engineering. Yet, a testbed engineer is an expert in his domain but rarely in data analysis. Thus, there is a need on a tool that can help the testbed engineers to readily analyse their data and gain valuable knowledge out of it. This knowledge can be for instance applied in for predictive maintenance, condition monitoring or for anomaly detection.

A durability test of an engine is divided in so-called cycles. The test cycle is defined by a given engine speed and is repeated multiple time until the target operating hours are reached. During a durability test, hundreds of measurement signals (in further text, channels) are measured and stored continuously. Basically, the results of each cycle should be the same. However, in real live scenarios this is often not the case. When this happens, we are talking about anomalies. Given that such a durability test can take up to 1000 hours and involves multiple sensors, makes it very hard to detect such anomalies at an early stage of the test.

Goals
The goal of this project is to provide data- and visual analytics tools that can be used to detect anomalies cyclic data of automotive testbeds. The methods should be able to deal with large multivariate time series data and be used by domain experts (i.e., engineers) with limited or no knowledge in data analysis and visualisations. Using the provided tools, it should be possible to monitor and forecast the conditions in each cycle of a durability test. To achieve this, it is necessary to not only use data produced by the sensors but also provided by the engineers. The latter is done by providing the engineers the opportunity to deliver feedback that is then incorporated into the system.

Approach
There exist several state-of-the-art algorithms that can be used to define a forecast model. This, however, requires an extensive literature review to analyse, which methods better applies to industrial data. Thus, within the scope of this project, we will investigate different algorithms to detect anomalies in multivariate time series and to forecast the durability test.

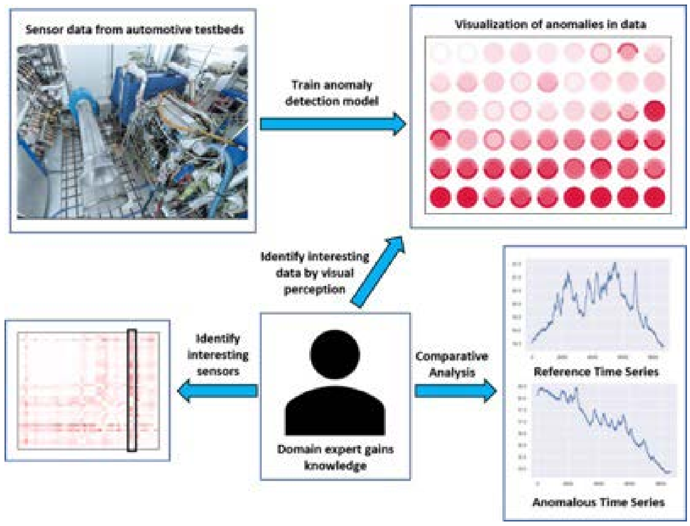
For the visual analytics tool, however, there exist powerful visualization libraries that provide different interactive 2D visualizations. These visualizations provide a good base to support user to visually navigate through the data and explore them to gain insights and draw important conclusion. However, the literature emphasizes the strength of a glyph-design when it comes to encode multivariate data and readily convey the spatial relationship.

Expected and Achieved Results
In this project, we propose an interactive visual analytics tool that displays the iterations of a durability test as a collection of color-encoded cycle glyphs. To do so, we aim to help the engineers to readily monitor the test and to detect potential anomalies. To achieve this, the engineer selects one glyph (or iteration) and the color of the remaining glyphs (or iterations) shows how much they deviate from the selected one: the darker the color of a glyph is the more it deviates from the selected one.

To calculate the anomaly score, we apply individual Machine Learning approaches (correlation-based anomaly detection, regression-based anomaly detection) which we have carefully selected considering their accuracy in detecting anomalies in multivariate time series data using 5-fold cross-validation.

Our visual analysis tool has been evaluated by the experts in the field with a pair analysis study. During this test, we investigated how the domain experts work with the proposed tool to detect anomalies on their daily analysis goals. The study has revealed that our tool aids the daily work in automotive testbed environments for two reasons. First, the visual analytics tool helps engineers to analyze the entire testbed dataset and not only a subset of well-known sensors. To do so, the engineers are able to investigate the correlation between the attributes (e.g., temperature and pressure sensor) and not only each attribute on its own. Second, using our tool the engineers are able to readily detect anomalies and explore their sources.

Summarized, our visual analytics tool provides promising methods to address the specific problems associated with automotive testbeds: analyzing multivariate time series and finding anomalies in reoccurring processes. The process and the results of the pair analytics study are published in BigVis2020, co-located with the 23rd International Conference on Extending Database Technology (EDBT 2020) & 23rd Intl. Conference on Database Theory (ICDT 2020. Furthermore, we evaluated the accuracy of the used algorithms for anomaly detection in multivariate time series data performing cross-validation.



Progress
This project officially started in April 2018. In it, Pro²Future is working with our Company Partners AVL, TU Graz Institute of Computer Graphics and Knowledge Visualisation, and TU Graz Institute of Interactive Systems and Data Science towards the creation of visual- and data analytics tool that can be used to detect anomalies cyclic data of automotive testbeds. We have already deployed our first prototype and evaluated it with the domain experts using data from an automotive engine testbed. Recently, we are testing different methods to analyse the root-cause of the anomalies. The most accurate method will be added in our visual analytics tool as an additional feature to identify the anomalies and established a timeline from the normal situation up to the time the anomaly occurred.

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AREA 3

StratP 3.4 SUPCODE

Supporting Cognitive Decision Making

Area 3 - Cognitive Decision Support Systems

Project ID:	StratP 3.4
Project Title:	Supporting Cognitive Decision Making
Project Lead:	Belgin Mutlu Pro2Future GmbH
Duration:	36 Months, 01.04.2019 - 31.03.2021
Strategic Volume:	100 %

Work Packages

WP 1: (Data) Analytics Methods Base & Comp. (Data) Analytics

WP 2: Decision Making Methods Base & Comp. Decision Making

WP 3: Secure Data Transmission

WP 4: Visual Analytics

WP 5: Dissemination

WP 6: Project Management

Academic Partners

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Industry 4.0 is considered as the "fourth industrial revolution" that either fully automatizes the production in the manufacturing industry or optimizes the collaboration of workers and machines. This is only possible when using different helping operators that facilitate the entire product life cycle, such as the decision support assistance systems. The power of the decision support systems lies on providing immediate assistance in situations where human judgment disregards the reactions times. This is considered as highly important particularly in risky and uncertain conditions where making a poor selection might cause catastrophic consequences for humans and the operating environment. What makes these systems cognitive is that they apply methods that simulate the estimation and the thinking process of the humans to choose one option from a set of possibilities (Definition of decision-making methods & computational decision making). In order to enable companies to utilize such assistance systems it is paramount that data collected at the production site and sent to an analytics entity is sufficiently secured. This can be achieved by providing a secure connection (Secure Data Transmission). Another concern when working with cognitive decision support systems is the transparency. The outputs of the decision-making processes are often too complex even for the experts, to understand. Yet, this lack of transparency can be a key problem in many applications. In order to tackle this issue, there is a need on tools that can be used for e.g., to explain/explore predictions/decisions made by the applied model(s) (Visual analytics).

Goals

To support human decision making, Area 3 defines two objectives:
(1) Combine data-driven approaches with configuration management methods and simulation environments in order to provide a reliable, trustworthy (data) basis for decision making.
(2) Provide this objective basis for decision making to humans in such a way that it takes into account their cognitive capabilities (e.g., information filtering in stress situations) as well as the situation/context in which the decision has to be made (e.g., within production process versus design process) in order to ensure timely and optimal decisions.

This strategic project fosters these Area objectives by strategic research activities considering the following context:

- A secure data transmission module will be applied and extended that allows to transmit data from production site to assistive system.
- To ensure that end-user understand why the system made a particular decision, this project further focuses on state-of-the-art visualization tools (2D, 3D) and visual analytics methods that are used, e.g., to explain/explore decisions made by system, the applied model(s) respectively.

- The visual analytics tool can further be applied to support scheduling, performance monitoring, and anomaly detection for the manufacturing systems that might help the end-user in her decision-making process.
- The simulation of scheduling and re-scheduling after expected (predictive maintenance) and unexpected changes (e.g. down-time of machines due to failures) allows for a better resiliency of manufacturing processes. The (further) development of algorithms can therefore help in optimizing the design of production systems and schedules for shop floors in cases of stochastic failures.

Approach

- **(Data) Analytics Methods Base & Computational (Data) Analytics** In order to build this reliable, trustworthy (data) basis for decision making we will create a collection of methods which allow us to collect data, facts, rules, engineering models, simulation models, etc. for a specific decision-making process within a specific application scenario. A specific challenge will be the integration of different methods into hybrid approaches which combine the advantages of the individual approaches, e.g. integration of model-based and data-based approaches. In order to prove the reliability and trustworthiness of the resulting data/facts basis it will be crucial to invest effort in the creation of training and test data sets which can be utilized as gold standards in order to benchmark the approaches and tools being developed.
- **Decision Making Methods Base & Computation Decision Making** Decision support has to be personalized (to the individual human cognitive capabilities), contextualized (to the specific decision situation), and domain-specific in order to lead to timely and optimal decisions. Proven computational decision-making support mechanisms are visual analytics, (data-driven) recommender and adaptable systems as well as simulations. We will combine these approaches in our computational prototypes for decision making support and develop application domain specific “industrial decision support” tools. As with all human-machine environments, careful evaluation of the resulting methods and tools in real-world environments will be crucial to the success.
- Applying data transmission security in decision support assistance systems used in the manufacturing industry methods to protect company data
- Using visual analytics and data analytics methods to support transparency in decisions/models made/applied by/in decision-support systems in manufacturing industry
- New insights gained about the application possibilities or interlocking of data analytics and visual analytics

Expected and Achieved Results

Decision support has to be personalized (to the individual human cognitive capabilities), contextualized (to the specific decision situation), and domain-specific in order to lead to timely and optimal decisions. Proven computational decision-making support mechanisms are visual analytics, (data-driven) recommender and adaptable systems. To contribute with regard to the later, we worked on a tool that should assist the users in analyzing their data by recommending the analytical methods to be used as next. For the recommendations, we observe the current analysis process and adapt the information space to what the user prefers and needs.

First, we worked on human-in-the-loop approaches for interactive data classification and comparison, by integrating active learning algorithms and similarity search methods with high-dimensional data analysis (see Figure 1). Second, we worked on novel concepts how eye tracking, as a novel user sensing modality, can be leveraged to detect user interest in visual data analysis, and support adaptive systems for data exploration. In a third line of research, we have developed concepts for user guidance in complex visual data exploration applications. A set of design guidelines was developed and analyzed.

In order to advance the field of Visual Analytics it is very important to collect and discuss the state-of-the-art in particular sub-fields. Together with collaborators from the University of Utah we surveyed existing work on multi-variate networks. In collaboration with US and UK colleagues we summarized the state-of-the-art on how to analyse interaction provenance data that is collected while users perform an interactive visual analysis. Besides these activities, we performed original research on the following topics: (1) guidance, (2) tabular data analysis techniques, and (3) onboarding. For the purpose of flexibly ranking tabular multi-variate data we continued the development of the Ordino visual analysis application, designed the novel Taggle visualization technique, and extended it with a support view that allows users to statistically confirm visual patterns. In cooperation with Prof. Aigner and his group at FH St. Pölten we designed and evaluated how to effectively onboard users to new visualization techniques.

Part of the project is related to the work in demonstrator project DP3. Classification and machine-learning are important methods for flexible production systems and adaptive scheduling. Here, data-driven approaches to optimize the configuration of production systems have been combined with simulation approaches used to determine the impact of changed configurations on the production system in the future. The new approach has been partially presented at the intermediate evaluation for the common research program of Pro2 Future and the Center for Digital Production.

The system consists of three components: (i) a classifier system capable of learning machine configurations given a particular product and the current state of the machine and tools, (ii) a scheduling and simulation system that is capable of re-organizing the production schedule if changes are required, and (iii) an integration component that links and controls the data-flows.

Web-based technologies are used to provide the technical connectivity. The scheduling component provides the means to rearrange the production schedule. However, this re-organization has again effects on the machine and tools usage.

Frequent Itemsets Mining is a fundamental mining model in Data Mining. It supports a vast range of application fields and can be employed as a key calculation phase in many other mining models such as Association Rules, Correlations, Classifications, etc. Many distributed parallel algorithms have been introduced to confront with very large-scale datasets of Big Data. However, the problems of running time and memory scalability still have not had adequate solutions for very large and “hard-to-mined” datasets. We proposed a distributed parallel algorithm named DP3 (Distributed PrePostPlus) which parallelizes the state-of-the-art algorithm PrePost+ and operates in Master-Slaves model. Slave machines mine and send local frequent itemsets and support counts to the Master for aggregations [1]. In the case of tremendous numbers of itemsets transferred between the Slaves and Master, the computational load at the Master, therefore, is extremely heavy if there is not the support from our complete FPO tree (Frequent Patterns Organization) which can provide optimal compactness for light data transfers and highly efficient aggregations with pruning ability. Processing phases of the Slaves and Master are designed for memory scalability and shared-memory parallel in Work-Pool model so as to utilize the computational power of multi-core CPUs. We conducted experiments on both synthetic and real datasets, and the empirical results have shown that our algorithm far outperforms the well-known PFP and other three recently high-performance ones Dist-Eclat, BigFIM, and MapFIM. Furthermore, a secure data connection framework has been developed, and it has been deployed at the pilot factory Vienna. To this end, a hardware component together with AVL and this component has been adapted to the context of data analytics in industrial settings.

Status / Progress

This project officially started in April 2018 and will last until April 2021. In it, Pro²Future is working with our Scientific Partners from Institute for Interactive Systems and Data Science (TU Graz ISDS), Institute of Computer Graphics and Knowledge Visualisation (TU Graz CGV), Institute of Computer Graphics (JKU ICG), Institute for Application-oriented Knowledge Processing (JKU FAW), PROFACTOR GmbH, and Evolaris next level GmbH to foster the research objectives of the area.

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AREA 4.1

MFP 4.1.1-1 CAVL-SD

Cognitive AVL: Smart Development

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.1-1
Project Title:	Cognitive AVL: Smart Development
Project Lead:	Konrad Diwold Pro2Future GmbH
Duration:	36 Months, 01.04.2018 - 31.03.2022
Strategic Volume:	10 %

Work Packages

WP 1: Information Model of the Product Development Process

WP 2: Information Infrastructure

WP 3: Application and Administration Tools

WP 4: Use Cases and Integration into AVL Infrastructure

WP 5: Dissemination

WP 6: Project Management

Company Partners

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Academic Partners

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Whether manufacturing physical products or delivering virtual services, corporations engage in a variety of sub-processes which are interrelated both within and across different phases of the production development process. In addition to achieving the core functional purpose of each step, each of these sub-processes generates information. This can be information about the product itself as well as information on the process. There are countless examples of information generated during production development. Corporations have already started to collect and store such information, with the expectation that this data might prove useful in the future as a means of generating valuable insights about production, and thus as a means of improving the production process and the generated product. Although this information may already be stored, most of it is not yet integrated into the overall production development process. In addition, such data is usually designed and used in a very specific context (e.g., monitoring the quality of the product during a particular production step) which leads to this data being generated in a wide range of proprietary or open formats (for example, as plain comma-separated-value files) which lack proper or standard facilities for preserving possibly important accompanying metadata about the production development process.
The MFP aims to develop a framework which allows (i) semantic modelling of the overall production development process and its underlying sub-processes, (ii) an interface to the production environment, to facilitate (iii) the active integration of process data into the semantic model, which leads to the potential for (iii) a data-driven optimization of the overall process. This will result in an application framework for cognitive production processes (linking the research with Area 4.2), which enables a process to act based on historical and currently perceived process information. The framework must provide tools and applications which allow creation, management, and adaptation of the models of the underlying sub-processes. Additionally, methods need to be derived which prepare and link process data generated in the various stages of the production process with the semantic model by means of meta-data. Once integrated into the process and linked to process data, the framework will be used to monitor and optimize key performance indicators (KPIs) of the production process. Automated reasoning (cognition) will be implanted to allow optimization of an individual process or of the overall process composition. To validate the ease of integration as well as the benefits of the framework and its underlying cognitive process, it will be tested in the context of dedicated use-case scenarios.

Goals

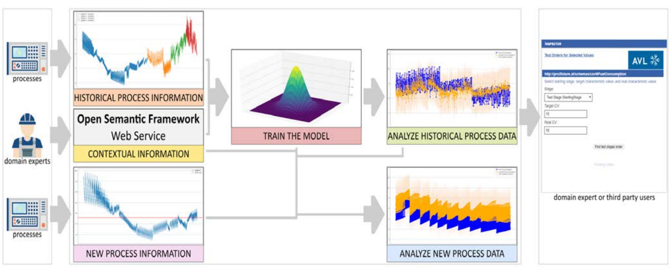
In order to remain competitive, companies constantly need to individualize and optimize their production development processes. One way of achieving this is by means of active integration and utilization of process data. For this, a foundation of models and tools is required that allow creation and management of data-related models, as well as a way to link such models with whatever process data is available. The goal of this project is to research how semantic technologies can be applied in the context of complex industrial processes. This requires the development of structures that enable easy mapping of the production development process into process-models. In addition, methods need to be established to allow the integration of unstructured data (such as time-series) into these process models. Such structures can be used as a basis for the optimization of individual processes and for the management of interdependent processes. Using such mechanisms allows a company to better understand the impact of individual steps of the product development process on the overall process, and to include this information as a driver of change in the development process. By providing predictions of the impact of potential changes on the production process, flexible and adaptive production processes are enabled.

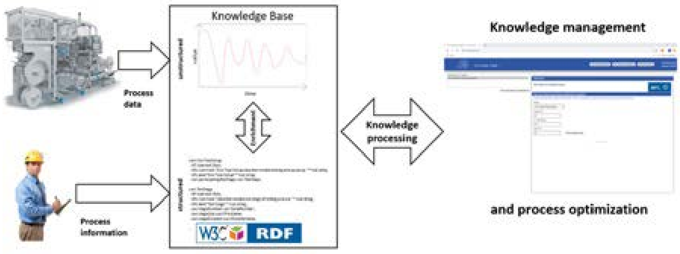
Approach

First appropriate information models and interfaces linking the production system to the semantic model framework are established. An information model is established as a group of interlinked resource description framework (RDF) ontologies. Each ontology maintains information relevant to a specific problem. Second, interfaces to the production system are designed and developed by extending the semantic model framework. This includes interfaces to process information which can be enriched with metadata; interfaces allowing the saving, access to, and management of process information; as well as interfaces which allow external applications to access the framework. In a third step prediction models are developed which allow to estimate the quality of processes and allow for their optimization.

Expected and Achieved Results

The product development process framework developed within this project will allow its users to model the overall production development process, while utilizing interfaces into the production environment allowing active integration of process data into the model to facilitate data-driven optimization of the modelled process. So far, the initial framework has been developed, and a simple product development process has been modelled. Based on this framework, we are currently investigating how structured data stored in the form of directed graphs of resources can be linked to unstructured data like time-series data produced during production, as well as how the system can be used to gain information about ongoing production to further assist smart management of the production process. After the concepts for this data integration are derived, the project will focus on the application of cognitive reasoning for process optimization. As the feasibility and benefits of such a semantic framework will be demonstrated and tested in the context of several specific use cases of the company AVL List GmbH, tools which allow the integration of the framework into their product development process will be developed.





Status / Progress

The project officially started in April 2018. Pro²Future is working with our Company Partner AVL List GmbH, the Institute of Technical Informatics at TU Graz, and the working group "Interaction and Communication-Based Systems" at the University of St. Gallen. The project was successfully kicked off and project joure fixes are held at regular intervals (approximately every 3 weeks). The first months of the project were used to establish an in-depth understanding of the production development process of AVL. In parallel, work on the semantic framework (Open Semantic Framework, OSF) started, which is used to semantically represent the product development process. OSF builds on top of the Resource Description Framework (RDF), a specification by the World Wide Web Consortium (W3C) that was designed for standardization of Semantic Web technologies. Within RDF, relationships between objects - henceforth "resources" - are described using subject-predicate-resource triples, with the predicate constituting the relationship between a subject and a resource (e.g., "Apple is-a Fruit"). Triples can be combined into directed RDF graphs which can be queried via query languages such as SPARQL to retrieve context information. OSF was used to implement a first version of a typical product development process. The project successfully developed ways to link structured and unstructured data by means of appropriate Web-based embedding of unstructured formats, which will enable this data to be used in the context of semantic technology platforms. Analyzing the provided testing data using graph based querying languages highlighted the limits of classical reasoning, with the reason being that the quality of data available in the various data lakes is not known, which limits any form of reasoning based on this data. To overcome these limits the project developed statistical methods (Bayesian Kernel Methods), which allow to predict the quality of process data with uncertain quality based on process data from later process stages where the quality is clear. The methods allow to assess the quality trajectory within a production development process and enable the application of reasoning. The resulting system, i.e., semantic reasoning enriched with machine learning (also known as model driven analytics) allows to use the best of two worlds, i.e. the reasoning capabilities associated with semantic technologies in combination with the modelling and classification capabilities provided by machine learning techniques, for the continuous optimization of production lifecycles.

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AREA 4.1

MFP 4.1.2-1 Simatic Failsafe 4.0

Development Processes and Tools for Cognitive Products

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.2-1
Project Title:	Simatic Failsafe 4.0
Project Lead:	Konrad Diwold Pro2Future GmbH
Duration:	24 Months, 01.12.2017 - 31.11.2019
Strategic Volume:	10 %

Work Packages

WP 1: Analysis of "State of the Art" and Familiarisation with the Siemens Environment

WP 2: Architecture and Design: System and Involved Elements

WP 3: Realisation of Demonstrators

WP 4: Dissemination and Exploitation

WP 5: Project Management

Company Partners

Siemens AG
DI Robert Egger (robert.egger@siemens.com)

Academic Partners

TU Graz, Institute of Technical Informatics
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The proliferation of industrial monitoring and control systems has led to the generation of a huge amount of data. It is predicted that 50 billion devices will be connected to the Internet by 2020, with the majority generating data in industrial settings that can be used to optimize industrial processes and to increase flexibility and integration along the product life-cycle. As the Internet of Things paradigm spreads into the industrial realm, we need to take into consideration additional aspects of industrial processes, such as their safety. The desire for better and faster production has created an industrial environment where people and cognitive machines collaborate in the same physical space. Consequently, the safety of people and of equipment has emerged as one of the greatest concerns for engineers in human-robot collaborative work settings. Manufacturers of Programmable Logic Controllers (PLCs) have invested a lot of resources in upgrading their PLCs, so that they are capable of detecting anomalies and of ensuring safety for the system and workers in the case of failures. Complex systems with multiple control units still represent a significant challenge, since the optimal safe state of the entire system needs to be determined and reached in time and space.

This MFP investigates how functional safety, availability, and maintainability can be improved in industrial environments. Analysis tools and methods stemming from the domain of predictive analytics will be applied to data sources already available in industrial fail-safe modules. Integrating data analytics (the main focus of Area 3's research) into industrial fail-safe processes denotes a prerequisite for future cognitive products and production processes, as it should fulfill the level of dependability which is required in industrial cognitive applications. In addition, the project investigates the required transition of traditional, static approaches to fail-safe operation into more challenging dynamic environments. This is necessary as smart factories which employ cognitive production processes are expected to exhibit non-static behavior, including rapid changes of tooling, physical movement of robots, and even the reconfiguration of entire manufacturing processes when required. Consequently, future fail-safe mechanisms must also be cognitive in order to adapt to or, ideally, anticipate these dynamics to guarantee fail-safe properties at all times. To do this, the project will investigate how to achieve an integration of predictive maintenance and fail-safe operation. This will result in novel cognitive Predictive Failsafe (PdF) mechanisms, which enable a system to adapt its fail-safe measures to new configurations and situations, as well as to forecast and mitigate errors.

Goals

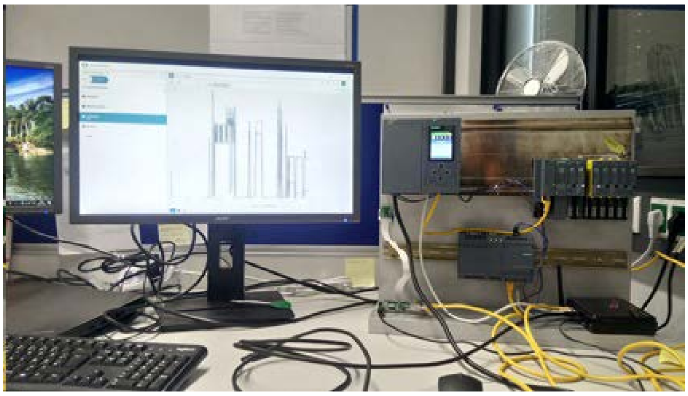
The overall goal of this project is to enhance fail-safe strategies for their application in cognitive production environments. This will be done by extending fail-safe strategies to include prediction of the mostly likely future states, thus leading to the new paradigm of Predictive Failsafe (PdF). PdF will give a system the ability to adapt its fail-safe measures to new configurations and situations that dynamically arise in smart factory environments, with the goal of protecting itself and its working environment, including human workers. In order to achieve the PdF paradigm two key elements are required: data sources for obtaining data that is relevant to fail-safe predictions, and prediction algorithms for analyzing this data. Identifying safety-relevant data sources and obtaining access to their data is not straightforward, since fail-safe components are usually deliberately shielded from the rest of an automation system. Obtaining this data is however crucial to PdF, especially since insufficient data quality can lead to incorrect conclusions and decisions, which is especially critical when dealing with safety-relevant data. Accordingly, one research goal of the project is to establish new mechanisms which provide a simple way of tapping into existing data sources in order to achieve the overall research goal of investigating how this data can be used in combination with machine learning and statistical methods to establish new, cognitive predictive failsafe mechanisms.

Approach

Being able to connect to and therefore utilize data sources is a key requirement for PdF. The project thus initially focused on the development of methods which allow access to and communication of fail-safe data produced by PLCs of the Simatic family. In a next step, existing fail-safe approaches and their underlying methods as well as application scenarios were studied in detail, providing a starting point towards the creation of new predictive fail-safe approaches for cognitive products and processes and establishment of their requirements. In order to demonstrate the applicability of these new approaches they will be implemented as demonstrators in a virtual environment that simulates real-life hardware and the services established in the earlier steps of the project.

Expected and Achieved Results

The first results of the project were the research, evaluation, and generation of the practice-relevant, future fail-safe scenarios for the Simatic automation device family. Based on our research, a first use case was established which concerns the application of the Simatic system in prospective collaborative industrial environments. As a result, a demonstrator for a dynamic fail-safe system was developed. The demonstrator is fully integrated into the Siemens production environment and demonstrates how selective, dynamic safety mechanisms can potentially be achieved based on Simatic automation in future collaborative workspaces. During the implementation of the use case, interfaces to access a Simatic's safety data as well as interfaces which allow connections with higher level services and systems (i.e., Siemens' TIA-portal and Mindsphere cloud environment) were established. These interfaces constitute a starting point for all further implementations in the project. The fail-safe mechanisms which are already implemented in the Simatic system are currently being investigated in detail. Our current research focuses on the application of machine-learning and statistical methods to improve fail-safe mechanisms as well as to establish a first iteration of predictive fail-safe mechanisms. Based on PdF mechanisms, the project aims to develop mechanisms for adaptive availability, which inform a user in advance about the likelihood of a given system entering a fail-safe state and offer concrete guidance on how to optimize the system to increase its reliability and availability. Predictive fail-safe will be used to establish services which allow Siemens to achieve improved context for any occurring fail-safe events within the Simatic product line, thus helping to further improve and optimize the performance of automation systems.



Status / Progress

This project officially started in December 2017. Pro²Future is working with company partner Siemens AG and the Institute of Technical Informatics at TU Graz towards the creation of novel predictive fail-safe approaches. The project was successfully kicked off and project joure fixes are held at regular intervals (every 3 weeks). In the initial phase of the project methods which allow the initial integration of data produced by Simatic fail-safe modules into the Simatic development environment as well as the Siemens edge and cloud environments (Mindsphere) were developed. Additionally, the concept of "Predictive Failsafe" was ideated, shaping the research direction of the project. Early work in the project concerned functional safety for collaborative workspaces.
This led to the development of a first demonstrator, which shows how dynamic fail-safe mechanisms can foster the collaboration of humans and machines in a cognitive production environment. To improve availability of existing safety solutions the project developed two new soft-error mitigation strategies. The first method concerns the application of parity bits in the context of existing 1oo2D failsafe architectures to enable such systems with error correction capabilities.

The second approach concerns the just in time (JiT) identification of read and write memory operations, prolonging the transfer of a system into its safe state until the system tries to read from a corrupted memory address. Besides the investigations into memory mitigation strategies the project also investigated how system parameters can be forecasted and monitored. A concept for temperature forecast and change point detection was developed, which allows to forecast environmental temperature based on temperature observed at the CPU of a failsafe module. In addition, change point detections were implemented to identify both slow (seasonal) and rapid (external influence: e.g., fire) changes in temperature, which would allow a system to contextualize its environment and trigger respective alarms. As a system's safety often depends on external components (such as sensor), the project how data analytics and statistics can be used to predict sensor aging. In this context a first demonstrator with artificial data has been developed and currently real sensor data is collected to enhance and extend the demonstrator.

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AREA 4.1

MFP 4.1.3-1 DRIWE

Dependable RF Communication Systems for In-Car Wireless Sensors

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.3-1
Project Title:	Dependable RF Communication Systems for In-Car Wireless Sensors
Project Lead:	Konrad Diwold Pro2Future GmbH
Duration:	36 Months, 01.03.2018 - 28.02.2021
Strategic Volume:	10 %

Work Packages

WP 1: Analysis of Constraints and Current State of In-Car RF Communication

WP 2: Investigation of new RF-communication systems

WP 3: Validation of New Concepts for Dependable RF-Communication Systems (Demonstrators, Design, and Implementation)

WP 4: Dissemination

WP 5: Project Management

Company Partners

AVL List GmbH
DI Peter Priller (peter.priller@avl.com)

Academic Partners

TU Graz, Institute of Microwave and Photonic Engineering
Prof. Erich Leitgeb (erich.leitgeb@tugraz.at)
Ass Prof.in Jasmin Grosinger (jasmin.grosinger@tugraz.at)

In order to establish new services and applications in the context of cognitive products and production processes, it is necessary to have information on the current and historical behavior of the target system. To monitor and gather such information, a dependable communication infrastructure and sensors with adequate sampling rate are needed. A good example for products which are currently undergoing rapid cognification are cars. Real-time monitoring of temperature, pressure, acceleration, voltage, chemical composition, or force, measured at a high sampling rate (100 Hz) within defined areas of the vehicle, constitute vital information which can be used for autonomous driving, online optimization of vehicle performance, or to guide future development of car components.

Vehicles are a challenging environment for sensor integration, partly because vehicles and their components (such as motors) are becoming increasingly compact, leaving little room for a sensor system. Given these spatial constraints, hardwiring the sensors within a motor block is not an option, although this would provide sensors with a continuous power supply and means of wired communication. For this reason, autonomous sensor solutions are required in the context of in-car communication, as they can provide flexibility in terms of sensor placement and energy supply. Current in-car communication is based on the Bluetooth Low Energy (BLE) standard, a radio frequency (RF) technology. BLE provides considerable flexibility regarding sensor placement and exhibits good power consumption characteristics. Unfortunately, the in-car environment contains many metallic surfaces which can result in unwanted reflections of RF wireless signals and a corresponding reduction in signal quality, thereby negatively impacting communication dependability.

This MFP investigates how the intelligent design of antennas and wireless RF communication systems can be optimized for in-car communication. Antennas, among other system components, play a crucial role in RF communication and can therefore be adapted to improve communication within a specific environment. Given the vast amount of different car designs and sensors, it is simply not possible to establish a one-design-fits-all antenna design and communication infrastructure for optimal in-car communication. To provide dependable communication, the underlying solutions must be individually adapted for their application environment to achieve optimal performance. The goal of the MFP is therefore to develop a framework which allows optimization of the antennas used by the sensors and the underlying communication network topology in an RF communication system, given a target in-car environment.

Goals

Dependable communication plays a key role in the implementation of cognitive services and applications. Given the increasing diversity of products and their designs, bespoke communication frameworks are necessary to achieve dependable performance. The automotive industry is a very good example for the continuing individualization of products. Given the vast differences of in-car environments, the development of in-car communication requires novel solutions in order to optimally adapt the communication system to its operational environment. In this project, RF wireless communication systems will be investigated in terms of their application in this domain.

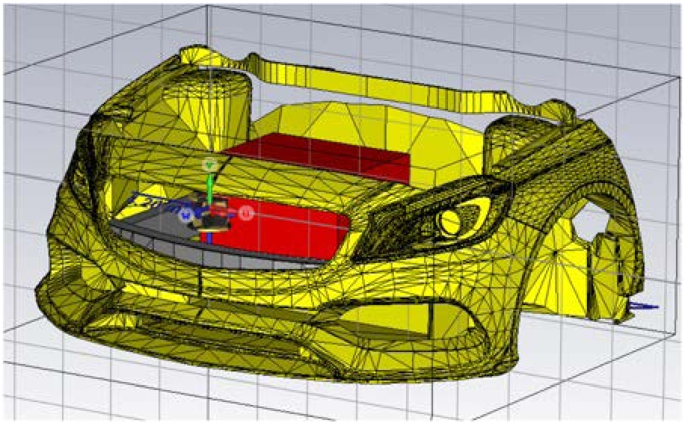
The project will establish key performance indicators (KPIs) which allow the assessment of wireless communication systems in in-car environments. Based on these KPIs, the project will research means of improving communication quality. As real-world experiments for in-car communication are very costly, the overall goal of the project is to establish a simulation framework for the automated design of in-car wireless communication systems. The envisioned framework will allow a specific in-car environment to be modelled, which can then be used to design the optimal RF wireless communication system for that environment. Optimization will be achieved by adapting antenna designs, antenna types, sensor positions, and communication network topologies for the target environment, resulting in bespoke, dependable communication solutions.

Approach

In order to establish a framework for the design of wireless communication systems for in-car environments, the following approach is taken. First, existing RF communication solutions for in-car environments are analyzed and KPIs are established to assess the quality and dependability of communication solutions. Second, a simulation framework is established, based on existing simulation software and parameterized using real-world sensor measurements. This simulation framework will be used to calculate the KPIs of a communication system in a specific in-car environment. It will then be used to iteratively generate, evaluate and optimize an antenna and communication system design until an optimum has been reached for a specific in-car environment.

Expected and Achieved Results

This project involves the systematic exploration and development of dependable RF communication systems for in-car environments. The project will result in an in-depth analysis of RF constraints in cars. So far, an initial electromagnetic simulation model of a motor block and a typical RF antenna has been established in order to investigate the behavior of reactive near-field and radiative near-field of antennas and the corresponding propagation effects within the in-car environment. Using standard RF sensor hardware, various tests and measurements were designed and are currently being performed in order to specify the characteristics of the sensor hardware. These experiments involve establishing the directional characteristics of the wireless sensor node and its antenna in environments with differing amounts of metallic elements. The results of the experiments will be used to tune the simulation. Once the simulation is aligned with this ground truth, the project will focus on the optimization of wireless sensor nodes in in-car environments. The optimization approach will investigate to what extent multiple-input and multiple-output (MIMO) antenna systems, different antenna types such as directed antennas and broadband antennas, as well as environment-specific antenna designs can improve the dependability of wireless in-car communication. The most promising concepts and technologies will be evaluated in the context of a demonstrator. The methodology resulting from this MFP is a first step towards establishing individualized, dependable wireless communication which is specifically adapted to the communication environment of a product and its production processes. The approach taken and results gained can be abstracted and used to facilitate future cognitive services in other branches.



Status / Progress

This project officially started in March 2018. Pro²Future is working with company partner AVL List GmbH and the Institute for Microwave and Photonic Engineering at TU Graz. The project was successfully kicked off and project jour fixes are held at regular intervals (approximately every 3 weeks). The first months of the project were used to establish an in-depth understanding of in-car environments. Based on this investigation a first electromagnetic simulation model of an in-car environment was established. In order to tune the simulation, various experiments with standard in-car sensors were performed. The resulting data will be used to specify realistic parameter values for future simulations and will be outlined in the first project publication. The next step that will be taken is the extension of the simulation environment. This will allow us to model a specific in-car environment and to design a RF wireless communication system which is optimized for this environment. An initial Matlab-Model for Wireless Communication Simulation was implemented which is based on the previously performed experiments as well as simulation data which was gained via CST experiments. To assess the quality of a given solution the calculation of a link budget is crucial, therefore a first draft for link budget calculation was established, which allows to evaluate the performance/requirements of various antenna types from simulation. In addition. the project investigated raytracing as a possibility to enhance the accuracy of the channel model.

First results of the project as well as an outline on the planned simulation framework (titled "Achieving Robust and reliable Wireless Communication in Hostile In-Car Environments") were presented at last year's international conference on Internet of Things. Additional project findings have been accepted at the IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (IEEE-APWC 2020) as well as the International conference on broadband communications for next generation networks and multimedia applications (CoBCom 2020).

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AREA 4.1

MFP 4.1.3-2 CSG
Cognitive Smart Grids

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.3-1
Project Title:	Cognitive Smart Grids: Dependable, Interoperable, and Adaptive Communication for Smart Grids
Project Lead:	Konrad Diwold Pro2Future GmbH
Duration:	24 Months, 01.04.2018 - 31.03.2020
Strategic Volume:	10 %

Work Packages

WP 1: Use Cases and Requirements Analysis

WP 2: Analysis and Evaluation of Smart Grid Communication Architectures

WP 3: Communication Architecture Recommender System

WP 4: On-line Adaption of Smart Grid Communication Systems

WP 5: Dissemination

WP 6: Project Management

Company Partners

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DI Andreas Lugmaier (andreas.lugmaier@siemens.com)

Academic Partners

TU Graz, Institute of Technical Informatics
Prof. Kay Römer (roemer@tugraz.at)

Due to the ongoing integration of distributed energy resources such as domestic photovoltaics into the existing distribution grid, conventional – mostly passive – monitoring and control schemes of power systems are no longer applicable. This has led to increased research into smart grid technologies, in particular how novel control schemes can be applied on a distribution-system level with the aim of implementing new services to mitigate the problems associated with distributed energy resources. Dependable communication plays a central role in smart grid operation.

The advent of the Internet of Things (IoT) paradigm has precipitated an ever-growing number of wireless communication technologies and protocols which could be utilized in the context of smart grid operation, among many other industrial IoT applications. The available protocols differ in their operation characteristics, including communication range, bandwidth, supported nodes, and network topologies. When designing a new smart grid control or monitoring scheme, the question arises which communication protocol is best-suited for the task. In addition, protocols must exhibit different levels of dependability in order to satisfy the given use-case requirements.

This MFP investigates potential wireless communication protocols for smart grid operation, and the results can be abstracted to their application in the context of industrial IoT applications in general. Dependable communication is a cornerstone for future cognitive products, as it allows them to gain information from the outside world beyond their own sensors, and to act in a distributed fashion. As cognitive services are often highly information dependent, using the right means of communication is crucial for their success The MFP thus aims to systematically investigate potential wireless protocols and their properties (such as bandwidth or dependability attributes) in order to derive a detailed analysis of available protocols. The analysis will be mapped into a knowledge base (ontology), which will be used to establish a recommender system to allow the specification of dedicated smart grid communication use-cases and support decisions about underlying communication protocols. This will be done by outlining the potential technical and economical performance of the available protocols in the context of the particular use case. In addition to building a recommender system, the project will research strategies which allow the online adaptation of protocols in case of any changes in their operation environment or requirements, as well as fail-over functionality to further improve dependability of smart grid operation.

Goals

Within this project, detailed characteristics of candidate wireless communication protocols for smart grid operation will be established based on typical smart grid monitoring and control application requirements. Once established, these characteristics will be used to (i) develop an ontology-based recommender system which allows a user to specify a dedicated smart-grid communication use-case, and to receive recommendations for suitable protocols for the implementation of that use-case. These recommendations are based on technical and economical feasibility. Additionally, the ontology will be used to (ii) enable a use-case dependent parameterization of the target protocol (i.e., recommending not only the protocol but also a suitable parameterization). The protocol characteristics will also be used for (iii) adaptation and reparametrization of protocol parameters during runtime as well as fail-over mechanisms (such as switching between communication protocols in case of a communication fault) in order to further strengthen and leverage the dependability of the protocols to the level required within a specific smart-grid operation use-case.

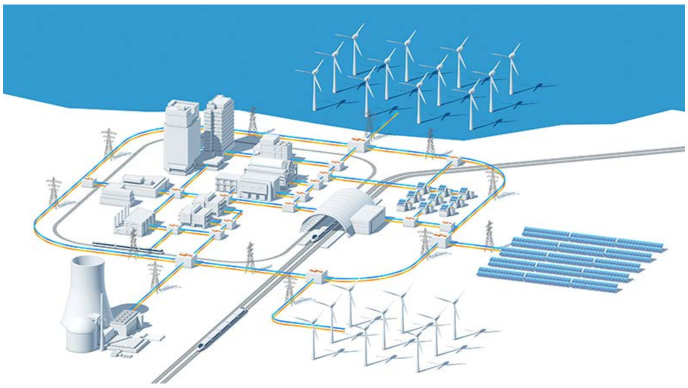
Approach

First, a detailed screening of smart-grid communication use-cases is performed. Based on this screening, required key performance indicators (KPIs) are established which allow the assessment of wireless protocols regarding their application in a smart-grid communication scenario. Second, an in-depth analysis of existing wireless protocols is performed. The protocols are investigated regarding their technical specification, their potential parameterization, parameter influence on protocol performance, protocol requirements and limitations, as well as available mechanisms to increase dependability. This information is used to establish an ontology of wireless protocols, which is used to implement a recommender system. Finally, the information is used to perform online adaptation of protocols.

Expected and Achieved Results

In the first phase of the project, smart grid monitoring and control use-cases were investigated to establish communication requirements. Use cases where wireless communication is used to control system-critical infrastructures impose very strict requirements on communication in terms of underlying availability, maintainability, reliability, and security. In the context of this analysis the need for retrofitting brown-field electric substations was identified, leading to the development of a Bluetooth low energy (BLE) based mechanism, which allows time-synchronized collection of data within secondary substations and an on-site configuration of sensors by authorized maintenance personnel.

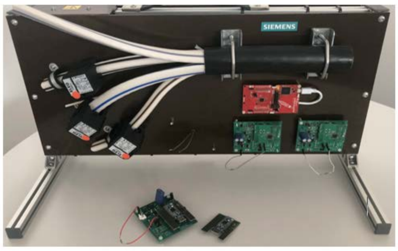
In a second step, an in-depth analysis of available wireless communication protocols was performed. The technical parameters of various relevant protocols, both short and long range, were established. The focus of this analysis was the protocols' dependability as well as external factors which impact their performance. The analysis was used to establish an ontology which represents the detailed protocol information. Ongoing research investigates how the ontology can be integrated into a semantic framework to implement a recommender system. The aim of this system is to allow a user to establish suitable protocols or protocol combinations for a defined communication use-case. Finally, the project focuses on establishing mechanisms which allow automatic parameterization of protocols for their application in the target use-case. In addition, the project aims to develop online methods to adapt a communication protocol in response to environmental changes to enable fail-over mechanisms for maintenance of connectivity and communication requirements.
As they will be generalizable beyond smart grid applications, the project results are a first step towards establishing dependable wireless communication for cognitive products and their production processes.



Status / Progress

The project officially started in April 2018. Pro²Future is working with company partner Siemens AG and the Institute of Technical Informatics at TU Graz. The project was successfully kicked off and project jour fixes are held at regular intervals (approximately every 2 weeks). The first months of the project were used to establish an in-depth understanding of smart grid communication use-cases. This investigation lead to the development of a Bluetooth-low-energy (BLE) based protocol which can be used for the time-synchronized collection of measurement data in secondary substations. This work resulted in a BLE based no low engineering demonstrator (see left picture in figure) for the monitoring of substations, which allows the easy application of sensor nodes within a substation environment and utilizes BLE to achieve a drift < 1 µs across all nodes, which constitutes a requirement for the calculation of complex system parameters such as phase angles across different sensor nodes.

In parallel, the semantic framework was prepared to implement the recommender system, which allows a user to specify a communication use-case and required KPIs. Based on this information the system computes the best communication technology (or best combination of communication technologies) to implement the use-case. After that the project focused on the development of tools for the cognitive management of communication in dynamic environments, by assessing current available link qualities (across multiple radios) and adjusting the used communication channels and payloads accordingly to achieve robust and dependable communication. This led to development of a demonstrator (see right picture in figure) which allows to assess and rate currently available link qualities (across multiple radios) and adjust the used communication channels and payloads accordingly to achieve robust and dependable communication. Currently the project focuses on refining and expanding the methods for dynamic communication channel adjustment utilizing metaheuristics and deep learning approaches.



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AREA 4.1

MFP 4.1.3-3 CONVENIENCE

Cognitive building automation infrastructure and services

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.3-3
Project Title:	Cognitive building automation infrastructure and services
Project Lead:	Konrad Diwold Pro2Future GmbH
Duration:	11,5 Months, 16.04.2020 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP 1: Requirements Analysis

WP 2: Secure, scalable and dependable communication

WP 3: Functional interaction software components

WP 4: Dissemination

WP 5: Project management

Company Partners

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Academic Partners

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Increased automation can be observed in many application domains. One good example for concepts stemming from digitalization and the domain of IoT precipitating automation is the home automation sector. Home automation also known as domotics allows a user to control lighting, climate, entertainment systems, and appliances in its home. The trend of home automation is fostered by appliances and products become smarter and connected, which allows their control and concertation. While new buildings often feature home automation systems an even bigger market in the context of home automation is retrofitting existing buildings and appliances with home automation solutions. Given the rapid development of new products, protocols and interfaces home automation system providers face a number of challenges. Their systems must allow an easy integration of an ever-growing market of solutions often differing in the used underlying technologies, for which they must provide dependable control solutions. In addition, given the private nature of home the systems must be secure and compliant to privacy regulations, while offering solutions which are easy and intuitive to use, scalable and optimize a living / office space in a non-intrusive way. This requires modular and flexible solutions which can be continuously adapted to allow for the integration of new products and appliances. Similar to other application domains of digitalization a dependable and secure connectivity between system and appliances is a key aspect. Wireless communication technology provides a good alternative to its wired counterpart as it ideally reduces installation and service efforts and does not intervene in the target environment. However, this freedom comes with a cost as wireless communication does not necessarily provide the required dependability e.g., due to interferences among devices communication solutions.

This MFP aims for developing an IoT strategy for an existing home automation solution. This concerns the evaluation and refinement of the underlying IT-infrastructure and services to allow for scalability, while providing dependable and secure communication and interaction between the systems entity. In addition, the project will develop wireless communication technology, which minimizes interference (in terms of communication) among the systems entities and adjusts to application scenarios to optimize the dependability of the overall system.

Goals

CONVENIENCE aims for the conception of an IoT strategy and roadmap for an existing home automation solution and provide is on new methods and concepts to (i) improve the scalability of the system in terms of the number of connections between the managed entities (ii) provide the seamless integration of IoT / mobile devices in the system, (iii) ensure a secure communication within the system and provide means to protect and shield sensitive data from attacks or data leaks and at the same time (iv) allow for a decentralized and concerted update to maintain the system (server, apps, studio, ...). In addition, the project will investigate the application of (v) a wireless over-the-air update functionality for the customer as well as the (vi) adaptivity and configuration of wireless communication among different radio technology.

Approach

First, a detailed screening of the existing system and its architecture is performed. Based on this screening the systems performance and accordingly the optimization potential will be established. In parallel to the system's screening the requirements of the application scenarios are identified. This information is used to establish a strategy for the system's improvement and highlights technological gaps in the context of wireless communication which can be tackled. The system's roadmap is developed in the context of existing and established open source software. Identified tech gaps in the context of dependable wireless communication (e.g., dependable over the air updates, cross technology communication) will be researched and the resulting technology will be tested in the form of demonstrators and real world use cases of the system.

Expected and Achieved Results

The outcome of the project is two-fold. On the one hand the project will result in a roadmap outlining the necessary steps and concepts to refine an existing home automation system to

- improve the scalability of the overall system
- allows for the seamless integration of new entities in the system
- ensure a secure communication and data storage within the system
- allow for decentralized updates.

As wireless communication plays an important role to realize such a system the project will also investigate f wireless communication in the context of home automation to provide and establish concepts/ methods for

- dependable wireless over-the-air update functionality
- the concertation of different wireless communication technology within a home automation system

The investigated topics will result in tech demos and prototypes and accompanying methodology which allow the transfer of the project results in other application domains.

Status / Progress

The project officially started in April 2020. Pro²Future is working with company partner HMI-Master GmbH and the Institute of Technical Informatics at TU Graz. The project was successfully kicked off and project jour fixes are held at regular intervals. The first months of the project were used to establish an in-depth understanding of the home automation use-case as well as the existing automation system. In addition, a screening of frameworks to enhance the scalability and dependability of the system was performed to establish the IoT-roadmap. Within autumn 2020 work on the communication aspects will start.

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AREA 4.1

StratP 4.1.4 PREDISCOVER
Unified Dependable Wireless Services for Cognitive Products

Area 4.1 - Cognitive Products

Project ID:	StratP 4.1.4
Project Title:	Unified Dependable Wireless Services for Cognitive Products
Project Lead:	Konrad Diwold Pro2Future GmbH
Duration:	36 Months, 01.03.2018 - 28.02.2021
Strategic Volume:	100 %

Work Packages

WP 1: Anwendungsfälle und Anforderungen an Kommunikation für intelligente Produkte

WP 2: Roadmap und offene Forschungsfragen

WP 3: Projektmanagement

Academic Partners

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Communication constitutes a key aspect of distributed cognitive automation systems and products, as it allows the exchange of information and services. In order to realize unified dependable wireless services for cognitive products, their application domains, scenarios and requirements must first be established. PREDISCOVER is a scoping study which aims to identify application scenarios of a unified dependable wireless service architecture across potential application domains. In PREDISCOVER the use cases are developed in order to derive the requirements and map these towards existing technologies, to 1) identify suitable technological candidates for implementing a unified dependable wireless service infrastructure for cognitive products, as well as 2) establish the open research questions in the respective communication technologies which need to be answered in order to establish such a service. PREDISCOVER thus aims to develop a research roadmap which will guide future research in the development of dependable wireless services for cognitive products.

Goals

The overall goal of PREDISCOVER is to identify the various application scenarios of a communication infrastructure for cognitive products, to then identify their requirements, and map to these scenarios and requirements onto existing technologies. This will allow the definition of open research questions which can be tackled in future strategic projects. Ultimately, this will lead to the realization of prototypical, unified dependable wireless services for cognitive products across a wide range of application scenarios. In summary, the goals are as follows: (1) Identification of application scenarios and requirements for a communication infrastructure for cognitive products; (2) Identification of open research questions regarding existing technologies; (3) Identification of cross-technology research questions; (4) Consolidation of application scenarios, technologies and research questions in a roadmap as a starting point for strategic follow-up projects.

Approach

PREDISCOVER is structured in two phases. Phase 1 is used to establish a wide range of use cases across potential application domains. These will be discussed and developed together with potential industrial partners as well as the academic partners in the project. In the second phase the functional and nonfunctional requirements of the use cases will be established. These requirements will then subsequently be used to identify suitable technology for implementing unified dependable wireless services and to identify current shortcomings (research gaps) which must be addressed in future projects in order to allow for a truly unified service architecture. As a whole, the project will therefore result in a roadmap outlining the direction of future strategic research that will lead to the envisioned communication infrastructure and services.

Expected and Achieved Results

In the course of the project, several communication scenarios have been developed. These scenarios span many domains (building automation, autonomous driving, factory automation, infrastructure monitoring) and are the result of discussions with ongoing project partners as well potential future project partners. A number of research articles are the direct result of the developed use cases. We are currently working on a mapping between technologies and use cases that will allow us to identify potential research gaps in these specific domains and to develop a general, strategic roadmap that will allow us to work towards developing a unified communication infrastructure for dependable wireless services.

Status / Progress

This project officially started in March 2018 and will last until April 2021. In it, Pro²Future is working with our Scientific Partners from Institute for Technical Informatics (TU-Graz ITI) and the Institute of Microwave and Photonic Engineering (TU Graz IHF) to foster the research objectives of the project. The first phase of the project was successfully completed and a number of communication scenarios for cognitive products and production processes have been developed in a wide range of application domains (building automation, autonomous driving, factory automation, infrastructure monitoring). As a first result of PREDISCOVER, the article "The Quest for Infrastructures and Engineering Methods Enabling Highly Dynamic Autonomous Systems", was presented at the 2019's European Conference on Software Process Improvement. Another publication which was established in the context of the project concerns communication-based localization mechanisms (e.g. by utilizing ultra-wide-band technology) an emerging trend and viable use case for communication infrastructures. The article co-authored with colleagues from the Institute of technical Informatics was accepted and presented at the IEEE 16th Workshop on Positioning, Navigation and Communications.

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AREA 4.2

MFP 4.2.1-1 CoExCo

Cognitive Polymer Extrusion and Compounding

Area 4.2 - Cognitive Productions Systems

Project ID:	MFP 4.2.1-1
Project Title:	Cognitive Polymer Extrusion and Compounding
Project Lead:	Prof. Georg Steinbichler, JKU Linz, Institute of Polymer Extrusion and Compounding DI Dr. Wolfgang Roland, JKU Linz, Institute of Polymer Extrusion and Compounding Mag. Bernhard Löw-Baselli, JKU Linz, Institute of Polymer Extrusion and Compounding Prof. Kurt Schlacher JKU Linz, Inst. of Automatic Control and Control Systems Technology
Duration:	48 Months, 01.04.2017 - 31.03.2021
Strategic Volume:	7 %

Work Packages

WP 1: Project Management

WP 2: Data Management System

WP 3: Inline-Compounding Film Line

WP 4: Pipe Coextrusion

WP 5: Corrugated Pipe Extrusion

WP 6: Gravimetric Dosing

WP 7: Coextrusion Blow Molding

WP 8: Dissemination

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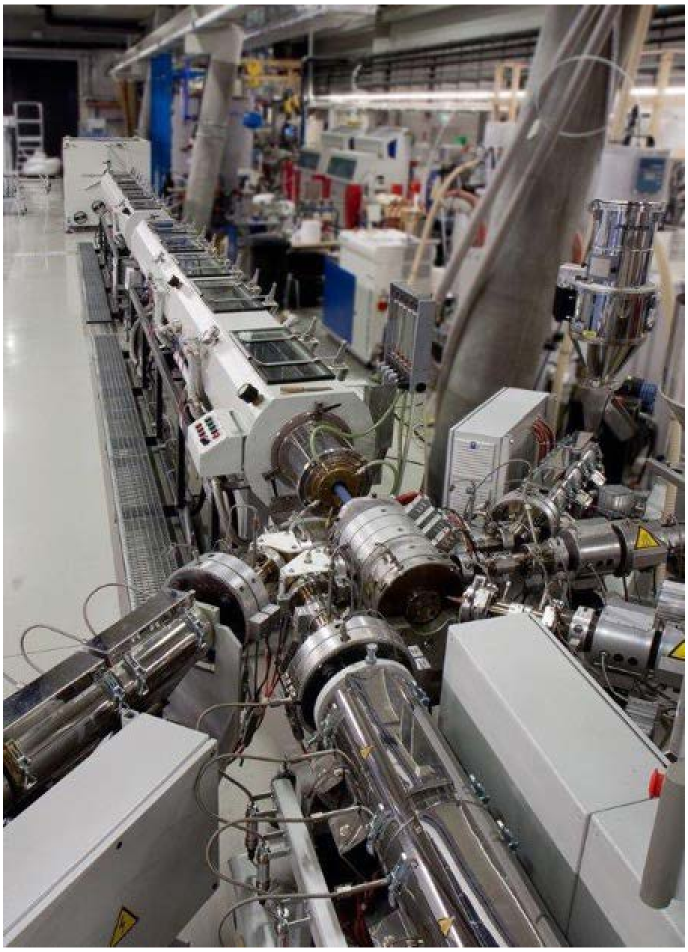
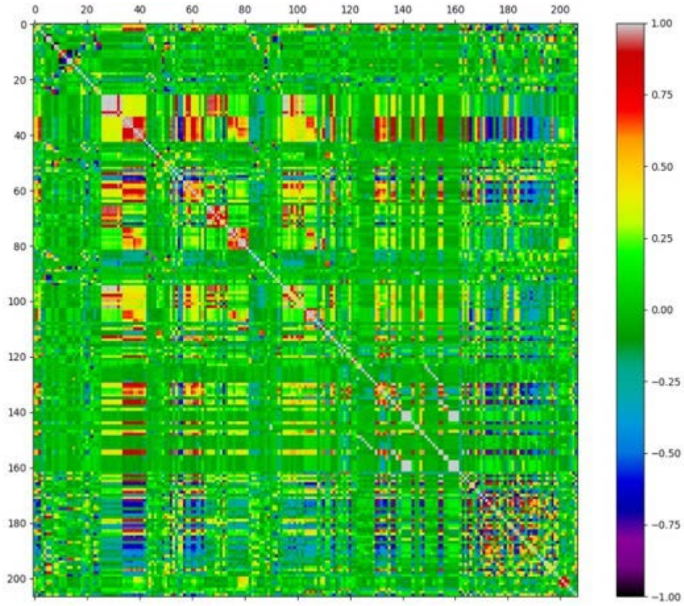
Dr.in Belgin Mutlu

Polymer processing plants show a nonlinear relation between extruders and downstream equipment, so this MFP will investigate and develop novel strategies for self-optimization in the field of film and sheet processing, pipe coextrusion, corrugated pipe processing, gravimetric dosing, as well as coextrusion blow molding. Up to now concepts of self-optimization for polymer processing lines are unknown in applicable complexity but the production systems would need almost real-time reactions based on process data. Therefore productivity and quality remains highly dependent on the operator in production runs as well as in ramp up after material change.





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Goals

As processes for polymer production show a high variety the goals of this MFP do either. The thermal management of extruders will be investigated, as extruder mostly have several but uncoupled heating zones. New control algorithms will be developed showing improved temperature management in heating as well as in operating change. Gravimetric dosing will also be investigated, as dosing units change to volumetric mode when shaked. Volumetric mode will become independent from screw characteristic lines by applying data based modeling and improvements to gravimetric mode sensitivity will be investigated. Online layer thickness measurement techniques will be developed to be applicable to corrugated pipe processing and the separation point inside the corrugator will be investigated for improvements of the cooling process. Furthermore, many simulations are intended to create a mathematical model that describes the process in a new way. As many polymeric products are processed by coextrusion, this process will be investigated by developing a novel coextrusion demonstrator to study the occurrence for layer rearrangements and flow instabilities in more detail under clear conditions. By means of data modeling and big data analysis new models for process design will be developed.

Approach

By combining approaches and data of physical/mathematical modeling (first principle), numerical calculation (e.g. network theory), CFD-simulations, experimental and production data, model-based control engineering, smart data mining etc. control concepts will be developed especially designed for polymer processing. Additionally, new sensor concepts will be applied or developed when needed for online process or quality control.

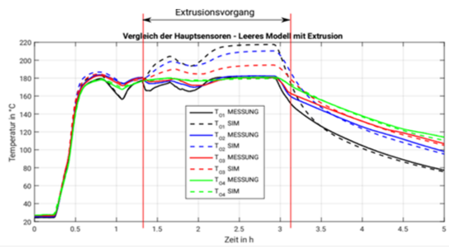
Expected and Achieved Results

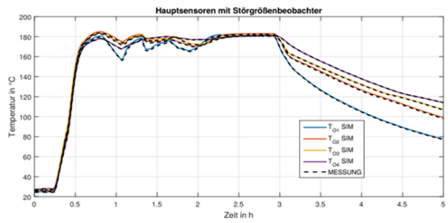
In modeling of corotating twin-screw extrusion a parametric study based on a dimensional analysis was performed, leading to novel parameters for the dimensionless conveying parameters of kneading blocks (like A1;see below). Consecuting research work will perfom a) an regression analysis leading to analytic expressions to enable fast and accurate screw design calculations and b) an experimental validation.

Additionally, to estimate the temperature distributions within the extruder and the heat flow between melt and barrel a model predictive control for start up, as well as set point and material change was developed. Experimental validation was performed showing good accordance when applying disturbance observer based on precise process model (see below).

Status / Progress

Due to personnel changes the project was slightly in delay and under serious reconfiguration, but in the meanwhile progress is as expected and good results have been achieved.





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AREA 4.2

MFP 4.2.2-1 ASP

Adaptive Smart Production - Part DP 1

Area 4.2 - Cognitive Productions Systems

Project ID: DP 1 WP1.5, MFP 4.2.2-1
Project Title: Adaptive Smart Production
Project Lead: Franz Haas
TU Graz, Institute for Production Engineering

Duration: 24 Months, 01.01.2018 - 31.12.2019
Strategic Volume: 10 %

Work Packages

WP 1: „Design-Benchmark“ of SOTA E-Powertrains

WP 2: „Production-Benchmark“ of One E-Powertrain

WP 3: Derivation of Assembly Process of One E-Powertrain

WP 4: Optimization Strategies in the Assembly Process („Design for Production“)

WP 5: Empirical Verification and Validation of the „Design for Production“

WP 6: Project Management

Company Partners

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Academic Partners

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TU Graz, Institute of Machine Components and Development Methods
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The rising share of e-mobility in the transport sector motivates this project. Electric vehicles, whether battery or hydrogen driven, are increasingly replacing combustion-based vehicles. Nevertheless, the absolute number of electric vehicles on the road is still relatively small. This is partly due to the fact that the infrastructure for re-charging is only slowly increasing, and partly due to the relatively high start-up costs of such vehicles. Making electric vehicles affordable requires the production costs to be lowered, which needs among other things to reduce the production cost of one of the main cost drivers: the electric powertrain. The electric powertrain consists of e-motor, gearbox and power electronics. Producing this electric powertrain at as low costs as possible is therefore a key requirement for future automotive development.

Reducing production costs requires changes in the production paradigms, in particular when compared to production of conventional powertrains. It is not sufficient to tailor existing manufacturing processes for increased efficiency. This is due to the fact that the current production lot size of electric powertrains is still at low volume meaning that the full capacity of the production machines cannot be used. Producing different electric powertrains in the same production plant solves the capacity problem, but new challenges emerge: How can different electric powertrains be produced in the same production plant without any delays, ramp-up time and defect parts? The answer is a new paradigm: adaptive and cognitive production.

Goals

The goal of this project is to establish a new paradigm of production systems for electric powertrain assembly. Future assembly lines for electric powertrains must be (i) **more flexible**, to achieve assembly of high variety and low volume parts. Combining the high variety with high efficiency addresses the issue of ramp-up time (converting the assembly process). (ii) **Reducing ramp-up time** is essential when assembling many different types of powertrains. In this project, reducing the ramp-up time will be investigated by combining simulation of the assembly process (virtual) with data from the real assembly process (physical). This combination will lead to a very significant and powerful prediction and better plannable ramp-up time. Decreasing production costs can also be achieved by (iii) **reducing assembly time**. This can be realised by (iv) **well-balanced human-machine interactions** in each assembly cell and assembly operation. Regarding this, the human factor (cognitive load in complex assembly process) needs to be considered. Hence, the cell itself needs cognitive and self-learning elements for engaging flexibly with the human worker. Flexibility is also a factor when connecting different assembly cells. Flexibility in terms of connected assembly cells will be investigated for (v) **adaptive and flexible plant and cell layout structure**.

Approach

Starting with the analysis of the architecture of different electric powertrains and their assembly processes, we will pinpoint similarities and differences. Based on this analysis, the requirements of the whole assembly line and each constituent assembly cell will be established. Existing technologies for each requirement (e.g. collaborative robots for heavy parts, cognitive guidance systems for complex assembly operations) will be investigated in more detail. After evaluation, a candidate solution will be implemented in an existing physical assembly process and in a simulation-based model. This proof of concept will present new adaptive and cognitive paradigms in production, as well as an overview of the weaknesses and challenges of this new paradigm.

Expected and Achieved Results

The achieved results in the project are a (i) **detailed description of the assembly workflow** of different electric powertrain architectures. This is necessary to demonstrate the diversity of assembly processes and to capture the limits of current assembly lines. Current trends in e-motor technology emphasize that new motor technologies will be used in future powertrains. Therefore, a further focus lies on (ii) **e-motor assembling**. The ongoing project should demonstrate an (iii) **assembly line concept for e-motor production** focusing on the attributes of adaptivity and flexibility. To investigate the impact of promising technologies on these attributes, an (iv) **innovative test bed for e-powertrains** must be developed. This test bed is built on the outcomes of (i)-(iii). In (iv) **a real-world assembly process** will be examined in more detail. In tandem, the test-bed evaluation provides information of high importance to improve both the assembly process and the design process of future electric powertrains. This information concerns efficient (v) **ramp-up and scale-up** scenarios for the assembly process. Based on these findings, future electric powertrains can be designed with a stronger focus on efficient assembling (“design for manufacturing”, “design for assembly”). To avoid information loss the findings should be reported in a (vi) **design checklist**.

Status / Progress

This project officially started in January 2018. In it, Pro²Future is working with our Company Partner AVL List GmbH and our scientific partners the Institute of Production Engineering and the Institute of Machine Components at TU Graz. We have held the project Kick-Off and started with investigation of different electric powertrain systems provided by AVL. During the investigation, new ideas were created and combined with the results of a brainstorming process: 12 high-potential product ideas for future electric powertrains (regarding the whole powertrain and the e-motor) were developed to increase the efficiency of the cooling process. Furthermore, four high-potential manufacturing ideas were created concerning a new method of stacking the electric sheet in e-motors. After that, the assembly workflow for different electronic powertrains was described in detail. This workflow highlighted two facts: the assembly process of an e-motor depends heavily on the type of motor, and the assembly process of different electric powertrains (excluding the e-motor) is usually very similar. In addition, the e-motor is typically purchased as a finished part, which is then assembled into the electric powertrain. Therefore, we have not investigated the e-motor in detail and instead focused on other electric powertrain components. In the next step of this project, the assembly line concept was developed. Starting with the big picture of the adaptive and flexible layout structures for the whole plant (bionic layout structures), we could deduce the assembly cell structure. We are currently investigating assembly cells, which need to be highly flexible in their design to contribute to the flexibility of the entire production process. We are also developing our simulation model and implementing new assembly strategies (with collaborative robots, learning machines etc.) for the cognitive production system.

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AREA 4.2

MFP 4.2.2-2 ASP 2

Adaptive Smart Production 2

Area 4.2 - Cognitive Productions Systems

Project ID:	MFP 4.2.2-2
Project Title:	Adaptive Smart Production 2
Project Lead:	Markus Brillinger Pro2Future GmbH
Duration:	36 Months, 01.04.2020 - 31.03.2023
Strategic Volume:	14 %

Work Packages

WP 1: Literature
WP 2: Requirement Definition
WP 3: Workflow, Instrumentation and Testing Design
WP 4: Simulation and Optimization
WP 5: Implementation
WP 6: Verification and Validation
WP 7: Dissemination
WP 8: Project Management

Company Partners

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Academic Partners

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The project MFP II 4.2.3-2 Adaptive Smart Production 2 (ASP 2), deals with two use-cases: fuel-cell component assembly and high-speed bearing system improvement.

The use-case fuel-cell component assembly in the field of mobility answers following questions:

- How to optimize fuel cell design for efficient production (DfM and DfA)?
- How to adapt existing production lines to follow market uptake?
- How far production processes from other domains can be used for fuel cells systems.
- Also, focusing on how to adapt existing production lines to follow the market uptake in the next 5 – 10 years.

Another use-case deals with high-speed bearing system for electric powertrains systems. Higher speed e-powertrains must be designed to achieve the required power as this must compensate for the downsizing of these e-powertrains. Another reason is that the demand and sales of these compact down-sized e-powertrains, which is increasing over time. However, the knowledge of production-based bearing behavior of high-speed bearing systems in the automotive industry is still at low level. Thus, this use-case focuses on the instrumentation and testing of a testbed to investigate the influence of manufacturing and assembly tolerances on the bearing system behavior, e.g. noise, vibration, harshness, load-based bearing temperature and the testbed behavior in general and operation conditions. To support this investigation, we will apply state of the art classification algorithms which uses image data in combination with other measurands taken on the testbed and gain system knowledge.

Following research questions will be answered:

- What is the impact in terms of design & validation to develop and validate designs & products able to provide the required performances?
- What is the impact in terms of production tolerance to reduce production costs?

All use-cases addresses the megatrends for customized products (which requires flexible production systems), silver society (requires an age-based workspace adaption) and personalized mobility (specific to the trend of e-mobility).

Goals

ASP2 has as its goal:

- To develop of innovative high-speed testbed and test procedures for e-drive components
- To develop innovative products and test methodologies for e-drive (bearing system in the loop)
- To create success stories supported by data analytics
- To develop innovative fuel cell designs enabling production cost decrease /performance increase
- To identify cost-efficient bipolar plate materials and corresponding manufacturing processes
- To adapt production lines from conventional ICE assembly line to FC stack and BOP assembly line (Production Engineering for AVL customers)
- To adapt production line for high-voltage battery assembly and fuel cell stack assembly (AVL BIC)
- To gain experience of production-based bearing systems behavior of high-speed bearing system
- To investigate the influence of manufacturing and assembly tolerances on the bearing system behavior, e.g. noise, vibration, harshness, load-based bearing system temperature and the testbed behavior in general
- To investigate the general conditions and new opportunities to use the classification algorithms based on image data in the field of testbed monitoring combined with mechanical measurands.

Approach

The project starts with a literature in the topic of fuel-cell component assembly line and for high-speed bearing systems for electric powertrains systems. The literature results will be summarized in a state-of-the-art report. The requirements definition for a new assembly line and the high-speed bearing systems will be set based on literature outcome and further developed with workshops along the company partners and Pro²Future on-site visits of the existing production system in mobility. Defining the requirements will embrace machine, process, human and quality aspects. Based on the requirements definition, the workflow, instrumentation and testing design will be initiated. After an ideation phase, possible concepts for assembly workflows for fuel-cell component and testing of high-speed bearing systems will be derived. These concepts will be evaluated based on the defined requirements. A simulation model proves the derived best-performing concept and is used for further optimization. This optimization is done via specific simulation tools, e.g. Siemens PlantSimulation for assembly and e.g. MKS for testbed. It helps to identify and focus on critical issues in highly flexible assembly lines and high-speed systems. The identification of the critical issues will be supported by the classification algorithms based on image data which are recorded on the testbed and illustrate the testbed behavior. The implementation phase transfers the optimized best-performing concept for both use-cases onto shopfloor and laboratory. Connecting and testing hard- and software systems (e.g. cobot with manufacturing execution system, high-speed bearing testbed) will be the focus in this workpackage. First, a prototype of the assembly line/workstation/ high-speed bearing systems is built-up at Institute of Production Engineering and Institute of Machine Component and Development Methods at TU Graz. Further from the prototype, two adaptions will be derived for the fuel cell component assembly and high-speed bearing systems, which are transferred to the company partner AVL. Verification and validation are followed post the implementation and installation of the two adaptions at company partners. The focus lies on acceptability of new technologies by the workers/testbed engineers, safety for workers, personalized workspace adaption as well as performance of high-speed bearing systems. The outcomes are two best-practice use-cases for design, implementation and evaluation of a high-performance fuel-cell assembly lines and Design-for-Production recommendations resulted by the high-speed bearing systems.

Expected and Achieved Results

The results of the project can be stated in general as a new approach for future assembly and production line adaptation, considering the human as a critical success factor. Implementation, verification and validation of a new production concept generates a unique selling proposition:

Considering the use-case fuel-cell component assembly, innovative fuel-cell designs (based on design for efficient assembly), which enables a decrease in production costs will be developed. Furthermore, a strategy for production line adaptation for high-voltage battery assembly, fuel cell assembly, e-motor and fuel-cell can be derived.

Considering the use-case testbed and test procedures for high-speed bearing systems for electric powertrains systems, a beyond state-of-the-art testbed will be developed to investigate the influence of manufacturing and assembly tolerances on the bearing system behavior. The generated data assists to optimize the assembly line towards increasing quality and flexibility. On the top of that, we will acquire knowledge about the conditions under which classification algorithms based on image data can be used combined with mechanical measurands.

Status / Progress

The project started at 01.04.2020 with a literature in the topic of fuel-cell component assembly line and for high-speed bearing systems for electric powertrains systems. The literature results will be summarized in a state-of-the-art report which will be published in Q3/2020.

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AREA 4.2

MFP II 4.2.2-1 SUPRA-1

Sustainable Production and Assembly 1

Area 4.2 - Cognitive Productions Systems

Project ID:	MFP II 4.2.2-1
Project Title:	Sustainable Production and Assembly 1
Project Lead:	Markus Brillinger Pro2Future GmbH
Duration:	3 Months, 01.04.2020 - 31.03.2023
Strategic Volume:	14 %

Work Packages

WP 1: Literature

WP 2: Power Peak Reduction

WP 3: Dissemination

WP 4: Project Management

Company Partners

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Academic Partners

TU Graz, Institute of Production Engineering
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SUPRA refers to efficient and sustainable production strategies in batch production, namely peak power reduction. In it,

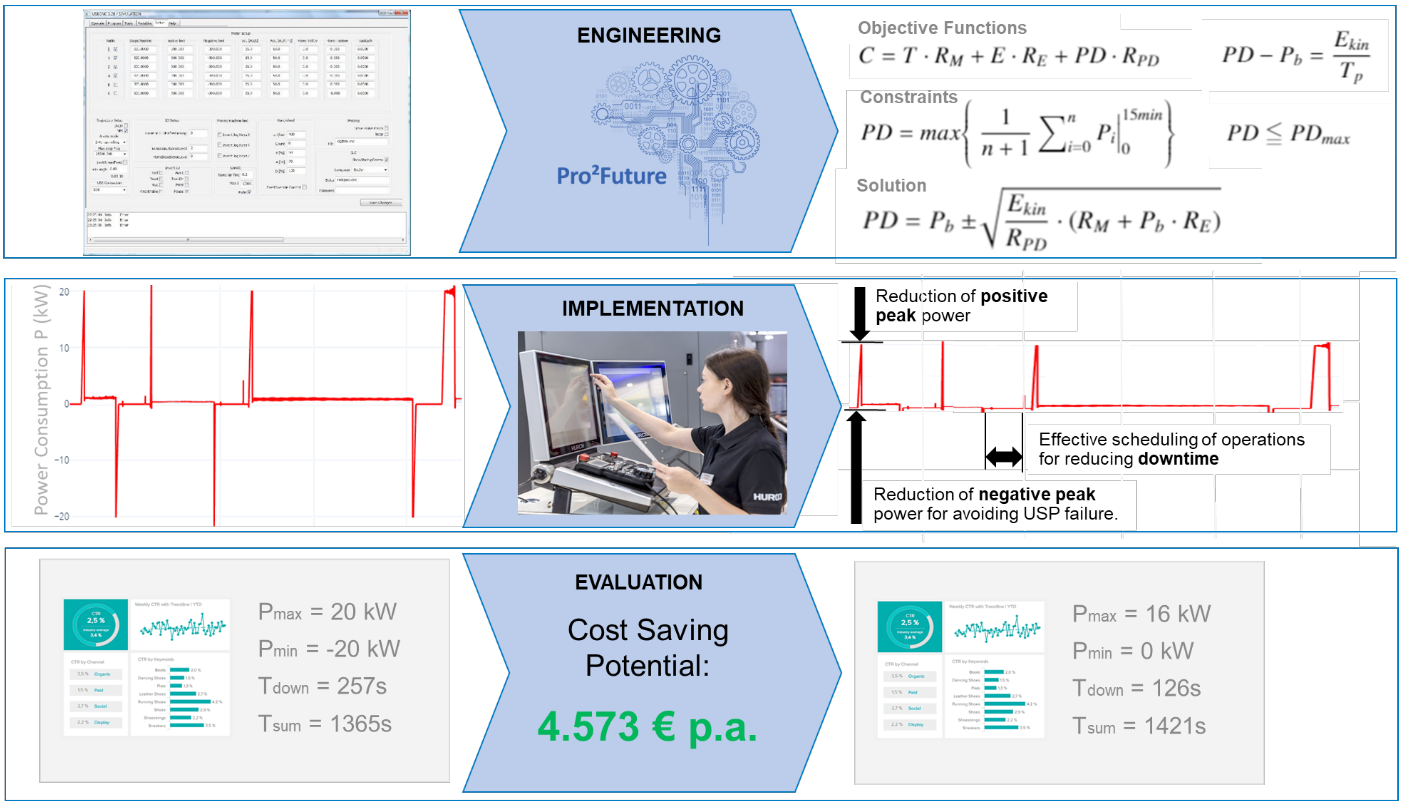
- existing KPIs for sustainable production, e.g. Franz Haas' EEC (energy efficiency coefficient) will be applied.
- new KPIs for sustainable production will be developed.

Goals

By using the methods developed in the strategic project "MFP 4.2.3 – Cognitive Energy Management Systems in Industrial Production Systems" (ENERMAN-1) executed in funding period 1, new methods for power demand peak detection (e.g. edge device) and prediction methods (e.g. machine learning), with high relevance to machining processes were investigated. Based on the this, the SUPRA project refers to develop and apply new sustainability-KPIs focusing on peak power reduction.

Approach

The project starts with a literature in the topic. After that, mathematic models for peak power reduction will be derived, implemented and evaluated at shop floor.



Expected and Achieved Results

SUPRA will reduce the peak power level of different machining processes, e.g. milling, ultrasonic machining, and therefore decreasing the power demand in batch production processes in metal industries. This will reduce the production costs and therefore achieve a competitive advantage for the participating company. The result will be a cornerstone in future sustainable production systems dealing with power demand and energy efficiency.

Status / Progress

The project started at 07.07.2020 with a literature in the topic of peak power reduction. First achieved results were already implemented at company partner's shopfloor.

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AREA 4.2

StratP 4.2.3-1 ENERMAN-1
Cognitive Energy Management Systems for Industrial Production

Area 4.2 - Cognitive Productions Systems

Project ID: StratP 4.2.3-1
Project Title: Cognitive Energy Management Systems for Industrial Production
Project Lead: Markus Brillinger
Pro2Future GmbH

Duration: 15 Months, 01.01.2019 - 31.03.2021
Strategic Volume: 100 %

Work Packages

WP 1: Definition Test Environment

WP 2: Definition Instrumentation Measurement and Analysis Tools

WP 3: Demonstrator

WP 4: Dissemination

WP 5: Project Management

Academic Partners

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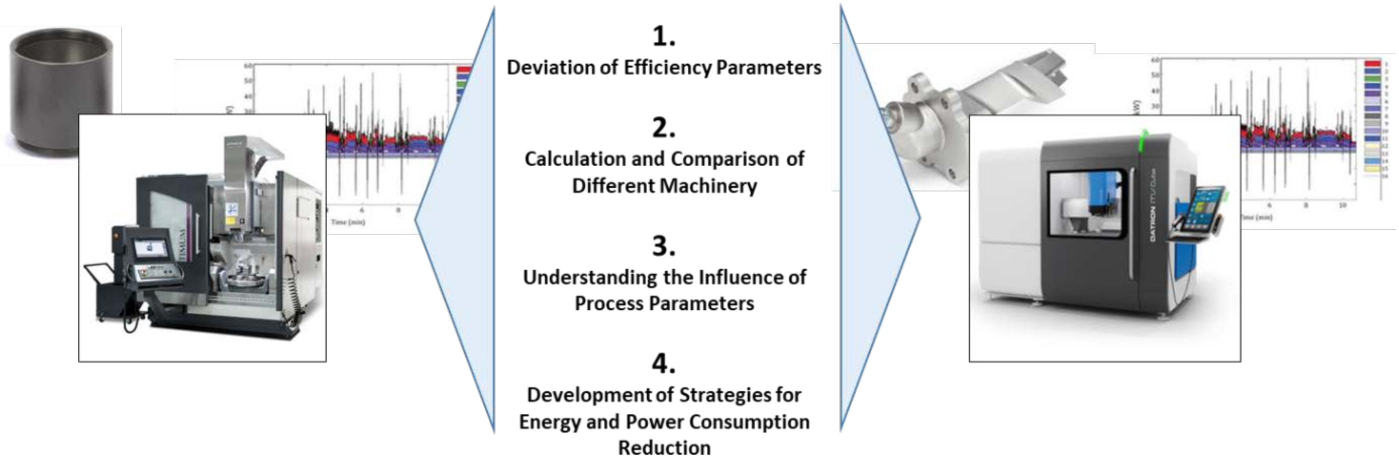
The research vision of the strategic project ENERMAN-1 deals with decreasing the energy consumption in continuous as well as batch production as a subject of extremely importance for all partner organizations. In it, the energy demand of machinery during manufacturing were investigated with respect to smoothing power peaks and lowering the total energy demand. The focus lies on reducing high energy consumption due to long process times and decreasing the high-power peaks due to acceleration of machinery components. The benefit of smoothing power peaks and lowering the total energy demand in production lies in a significant cost reduction of the process. The vision of this project is to provide a scientific output leading to a significant reduction of energy and power consumption of the production systems.

Goals
ENERMAN-1 has as its goal the detection and reduction of energy demand of produced parts in batch and continuous production systems. The research goal is to develop a standardized new energy management system within a continuous extrusion and batch production system by (i) derivation of efficiency parameters (e.g. efficiency labels, retrofit factor, …) for different manufacturing processes (subtractive, polymer extrusion) and (ii) calculate and compare different machinery at JKU Linz as well as TU Graz. To increase the (iii) understanding of influence of processing parameters on energy consumption (e.g. an optimum barrel temperature setting to polymer melt quality) will help to (iv) develop strategies for energy and power consumption reduction for typical batch and continuous production (e.g. power factor correction, peak load optimization, drive technology with excellent efficiency class, thermal insulation, split and adapted circuits for process cooling). Creation of (v) academic fundamentals are the basis for industry cooperation in future.

Approach
The research approach and method of this strategic project is focused on the ICT-supported strategies, methods and model-based control technologies by application of experimental and computational modelling within a continuous and batch production system. Key technologies will be the wireless infrastructure and data mining. Special strategies to reduce the energy consumption represent the framework of a new system that is also influenced by the results of the other Pro²Future working groups (e.g. cognitive decision making).



Expected and Achieved Results

The results of ENERMAN-1 can be summarized as follow:
A unique test system with intelligent evaluation software for continuous and batch production are installed at Living Lab for polymer extrusion and compounding at JKU Linz, for batch production within the new pilot factory at TUG with the brand name “smartfactory@tugraz”. In continuous production a new metrology method for identifying the length-based energy input in an extrusion process were developed. The new metrology method helps to identify the energy input in an extrusion process which is crucial for verification of the process simulation.

Indicators for energy efficiency for a representative set of production technologies were developed and evaluated in case studies. Based on this case studies guidelines for energy efficient product design are under progress. These guidelines developed in ENERMAN-1 will evolve the competence of the center and covers long-term industrial interests. The project results can be exploited in four business cases: (i) distributing the knowledge via training and education, (ii) providing the developed hard- and software, (iii) consultative providing the gained knowledge and (iv) performing truly-joint research cooperation projects.

Status / Progress

Definition of Test System
In it, the state-of-the-art of science and technology for energy management systems for continuous and batch production were identified. Furthermore, the research gap for energy management systems were determined. Two specific use-cases were defined, one in continuous polymer extrusion process and one in batch production.

Testing Equipment and Analysis Tools
This workpackage embraced an approach for negotiating or mitigating the research gap by combining the domain knowledge of mathematics and control algorithms (REGPRO, JKU Linz), extrusion (IPEC, JKU Linz) and batch production (IFT, TU Graz) as well as measurement instrumentation and testing (University of Maribor). The outcome of this workpackage was the selected hardware (sensors, control hardware…), the programmed software (control algorithms,…) and developed key performance indicators (energy saving potential, retrofitting factor,…) based on the requirements specified in this workpackage.

Demonstrators
In this workpackage methodologies for energy management were developed which are still in implementation phase for continuous polymer extrusion processes at LivingLab (at JKU Linz) and for batch production in smartfactory (at TU Graz). The implementation process covers the installation of selected hardware (sensors, control hardware…) and software (control algorithms,…) for the detailed use-cases of continuous polymer extrusion and batch production. In nearer future the workpackage will be finished. The deliverables will be the installed energy management system in both production systems.

After this, the implemented system and their limits will be explored. Based on the developed key performance indicators (energy saving potential, retrofitting factor…), practical energy saving recommendation will be derived. Furthermore, a strategy for improving the energy management systems in continuous and batch production must be given. The outcome will be an energy improvement-report and a strategy for enhancing the developed energy management system.

Dissemination
The project results are still under dissemination at high-ranked scientific conferences and journals with high impact factor.

Project Management
This workpackage is ongoing along the complete project runtime. In it, the project manager deals with organizational and scientific issues (e.g. meeting and appointment organization, controlling costs target, responsibility for publication strategy…).

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Role:
MFP 3.1 OnDaA: WP 1, WP 2

Expertise:
Predictive Analytics, Time Series, Machine Learning

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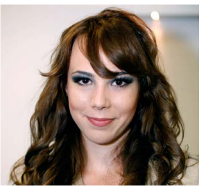
Role:
SINPRO, OnDaA, StratP

Expertise:
Visual Data Science, Visual Data Analytics



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Role:
MFP 3.1 RedUsa: WP 1 - WP 5

Expertise:
Data Analytics,Visual Analytics

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Role:
MFP 3.2 ConMon: WP1 - WP 5

Expertise:
Visual Analytics, Condition Monitoring, Predictive Maintenance

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Role:
MFP 3.1 SINPRO: WP 2 and WP 5, Prediction Model

Expertise:
Data Analytics, Data Mining, Software Engineering, Machine Learning

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Role:
SINPRO, OnDaA

Expertise:
Cognitive Decision Support, Visual Data Analytics, Uncertainty Visualisation

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Role:
SINPRO

Expertise:
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Role:
MFP 3.2 GuFeSc: WP 1 - WP 5

Expertise:
Predictive Maintenance in Multi-Component Systems

HUMAN RESOURCES

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Role:
MFP 4.1-1 Cognitive AVL: WP Guidance, involved in WP 1 - WP 6

MFP 4.1-2 Simatic Failsafe: WP guidance, Involved in WP 2 - WP 5

MFP 4.1-3 CSG: WP Guidance, WP Feedback, Involved WP 1 - WP 6

Expertise:
IoT, Semantic Web Technologies, System Integration

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Role:
MFP 4.1-1 Cognitive Products: Scientific Guidance

MFP 4.1-2 SimaticFailsafe : Technical Guidance

MFP 4.1-3 CSG: Technological Feedback

Expertise:
IoT, Dependable Communication

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Role:
MFP 4.1-1 Cognitive AVL: Technical Guidance, involved in WP 1 - WP 5

Expertise:
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Role:
MFP 4.1-3 DRIWE: Technological Guidance, involved in WP 1, WP 2, WP 4

Expertise:
Antenna Design, Near Field Communication, Simulations

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Role:
Academic Partner Area 1, Area 4.1

Expertise:
Optoelectronical Communication Engineering, Modelling, Simulation and Computer-Aided Design in Engineering and Management

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MFP 4.1-1 Cognitive AVL: Involved in WP 1 - WP 5

Expertise:
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Role:
Cognitive Smart Grids

Expertise:
Networked Embedded Systems, Internet of Things, Cyber-Physical Systems, Wireless Sensor Networks, Dependability

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MFP 4.1-3 DRIWE: Involved in WP 1 - WP 4

Expertise:
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Role:
MFP 4.1-2 SimaticFailsafe: Involved in WP 2, WP 3

Expertise:
Embedded Systems, Localization Mechanisms, IoT

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Role:
MFP 4.1-2 Simatic FailSafe: : Involved in WP 1 - WP 4

Expertise:
FailSafe Mechanisms, Embedded Systems, System Integration

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Role:
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Expertise:
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HUMAN RESOURCES

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Role:
MFP 4.2 2: Adaptive Smart Production: WP 1 - WP 6

Expertise:
Production & Manufacturing

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Role:
MFP 4.2.2 ASP
StratP 4.2.4 ENERMAN

Expertise:
Advanced Manufacturing

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Role:
MFP 4.2 2: Adaptive Smart Production: WP 1 - WP 6

Expertise:
Production & Manufacturing

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Role:
MFP 4.2 2 Adaptive Smart Production: WP 1, WP 4, WP 5

Expertise:
Design

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Role:
MFP 4.2 1 CoExCo: WP 1 - WP 8

Expertise:
Polymer Processing

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Role:
MFP 4.2 1 CoExCo: WP 1 - WP 8

Expertise:
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Role:
MFP 4.2 2: Adaptive Smart Production: WP 1 - WP 6

Expertise:
Design

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Role:
CoExCo, ENERMAN

Expertise:
Polymer Processing

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MFP 4.2 2: Adaptive Smart Production: WP 1, WP 4, WP 5

Expertise:
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MFP 4.2 1 CoExCo: WP 2, WP 3, WP 8

Expertise:
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Role:
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Expertise:
Polymer Processing

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Role:
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Expertise:
Optimal Trajectory Planning for Plastic Extruders, Temperature Control of Plastic Extruders, Thermal Models Based on Finite Element Methods

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Role:
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Expertise:
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Role:
MFP 4.2 2: Adaptive Smart Production: WP 1, WP 4, WP 5

Expertise:
Design

HUMAN RESOURCES

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PUBLICATIONS 2017

Scientific Journal Papers

Weichhart, G., Stary, C., and Vernadat, F.: Enterprise modelling for interoperable and knowledge-based enterprises. International Journal of Production Research 56.8 (2018): 2818-2840. 2018. https://doi.org/10.1080/00207543.2017.1406673

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Peer-Reviewed Conference Papers

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Talks & Presentations

Ferscha, A.: Industrie 4.0 - Digitalisierung der Arbeitswelt. Industrie 4.0 - Digitalisierung der Arbeitswelt. Linz, Austria. 2017.

Ferscha, A.: Tatort Digitalisierung: Menschliche Motive und ihre symbiotischen IT-Systeme. Tiroler IT-Day. Innsbruck, Austria. 2017.

Jungwirth, F. and Murauer, M.: Gaze-based Action Zones: A universal interaction modality for IoT devices. Workshop Talk on Handling the Intenret of Things (in conjunction with IoT 2017). Linz, Austria. 2017.

Mayer, S.: The Cognitive Internet of Things - a New Era of Computing and Networking? Panel 15th International Conference on Advances in Mobile Computing & Multimedia. Salzburg, Austria. 2017.

Thalmann, S.: Decision support with augmented reality in the context of Industry 4.0. Augmented and Virtual Reality Symposium. Kufstein, Austria. 2017.

Thalmann, S. and Mayer, S.: Panel Industry 4.0. Pro²Future at the Internet of Things. Linz, Austria. 2017.

Finished PhD Theses

Gollan, Benedikt: Sensor-based Online Assessment of Human Attention

Finished Master Theses

Murauer, Michaela: Natural Pursuits for Eye Tracker Calibration

Jungwirth, Florian: Contour-Guided Gaze Gestures: Eye-based Interaction with Everyday Objects

PUBLICATIONS 2018

Scientific Journal Papers

Chegini, M., Shao, L., Gregor, R., Lehmann, D.J., Andrews, K., and Schreck, T.: Interactive visual exploration of local patterns in large scatterplot spaces. Computer Graphics Forum, Vol. 37, No. 3, pp. 99-109. Wiley. 2018. https://doi.org/10.1111/cgf.13404

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Vagliano, I., Günther, F., Heinz, M., Apaolaza, A., Bienia, I., Breitfuss, G., Blume, T., Collyda, C., Fessl, A., Gottfried, S., Hasitschka, P., Kellerman, J., Köhler, T., Maas, A., Mezaris, V., Saleh, A. Skulimowski, A.M.J., Thalmann, S., Vigo, M., Wertner, A., Wiese, M., and Scherp, A.: Open Innovation in the Big Data Era With the MOVING Platform. Journal IEEE MultiMedia, Volume 25, Issue 3, pp. 8-21. IEEE. 2018. https://doi.org/10.1109/MMUL.2018.2873495

Weichhart, G., Stary, C. and Appel, M.: The digital Dalton Plan: Progressive education as integral part of web-based learning environments. Knowledge Management & E-Learning: An International Journal, Volume 10, Issue 1, pp. 25-52. 2018. https://doi.org/10.34105/j.kmel.2018.10.002

Peer-Reviewed Conference Papers

Fast-Berglund, A., Thorvald, P., Billing, E., Palmquist, A., Romero, D. and Weichhart, G.: Conceptualizing Emodied Automation to Increase Transfer of Tacit knowledge in the Learning Factory. IS 2018, IEEE 2018 International Conference on Intelligent Systems, pp. 358-364. IEEE. 2018. https://doi.org/10.1109/IS.2018.8710482

Ciortea, A., Mayer, S., and Michahelles, F.: Repurposing manufacturing lines on the fly with multi-agent systems for the web of things. AAMAS 2018, 17th International Conference on Autonomous Agents and MultiAgent Systems, pp. 813-822. ACM. 2018.

Diwold, K., Mayer, S., Einfalt, A., Parreira, J. X., Hodges, J., Anicic, D., and Mosshammer, R.: Grid Watch Dog: A Stream Reasoning Approach for Lightweight SCADA Functionality in Low-Voltage Grids. IoT 2018, 8th International Conference on the Internet of Things, Article No. 12, pp. 1-8. ACM. 2018. https://doi.org/10.1145/3277593.3277601

Koutroulis, G. and Thalmann, S.: Challenges from Data-Driven Predictive Maintenance in Brownfield Industrial Settings. BIS 2018, International Conference on Business Information Systems, pp. 461-467. Springer, Cham. 2018. https://doi.org/10.1007/978-3-030-04849-5_40

Haslgrübler, M., Ferscha, A., and Heftberger, J.: Transferring Expert Knowledge through Video Instructions. PETRA 2018, 11th PErvasive Technologies Related to Assistive Environments Conference, pp. 358-362. ACM. 2018. https://doi.org/10.1145/3197768.3201571

Haslgrübler, M., Jungwirth, F., Murauer, M., and Ferscha, A.: Visually Perceived Relevance of Objects reveals Learning Improvements and Task Difficulty. PETRA 2018: 11th PErvasive Technologies Related to Assistive Environments Conference, pp. 265-268. ACM. 2018. https://doi.org/10.1145/3197768.3201520

Huemer, C., Kappel, G., Wimmer, M., Proper, H. A., Reich, S., Behrendt, W., Thalmann, S., Weichhart, G., and Zoitl, A.: Interoperability and Integration in Future Production Systems. CBI 2018, IEEE 20th Conference on Business Informatics, Vol. 2, pp. 175-177. IEEE. 2018. https://doi.org/10.1109/CBI.2018.10067

Iglesias-Urkia, M., Casado-Mansilla, D., Mayer, S., and Urbieta, A.: Enhanced publish/subscribe in CoAP: describing advanced subscription mechanisms for the observe extension. IoT 2018, 8th International Conference on the Internet of Things, Article No. 14, pp.1-8. ACM. 2018. https://doi.org/10.1145/3277593.3277594

Iglesias-Urkia, M., Casado-Mansilla, D., Mayer, S. and Urbieta, A.: Validation of a CoAP to IEC 61850 Mapping and Benchmarking vs HTTP-REST and WS-SOAP. ETFA 2018, 23rd IEEE International Conference on Emerging Technologies and Factory Automation, Vol. 1, pp. 1015-1022. IEEE. 2018. https://doi.org/10.1109/ETFA.2018.8502624

Jungwirth, F., Haslgrübler, M., Murauer, M., Gollan, B., Elancheliyan, P., and Ferscha, A.: EyeControl: Towards Unconstrained Eye Tracking in Industrial Environments. SUI 2018, Symposium on Spatial User Interaction, pp. 177-177. ACM. 2018. https://doi.org/10.1145/3267782.3274673

Jungwirth, F., Haslgrübler, M., and Ferscha, A.: Contour-guided gaze gestures: using object contours as visual guidance for triggering interactions. ETRA 2018, Proceedings of the 2018 ACM Symposium on Eye Tracking Research & Applications, Article No. 28, pp. 1-10. 2018. https://doi.org/10.1145/3204493.3204530

Jungwirth, F., Murauer, M., Haslgrübler, M., and Ferscha, A.: Eyes are different than hands: An analysis of gaze as input modality for industrial man-machine interactions. PETRA 2018, 11th PErvasive Technologies Related to Assistive Environments Conference, pp. 303-310. ACM. 2018. https://doi.org/10.1145/3197768.3201565

Kajmakovic, A., Zupanc, R., Mayer, S., Kajtazovic, N., Hoeffernig, M., and Vogl, H.: Predictive Fail-Safe - Improving the Safety of Industrial Environments through Model-based Analytics on hidden Data Sources. SIES 2018, 13th International Symposium on Industrial Embedded Systems, pp- 1-4. IEEE. 2018. https://doi.org/10.1109/SIES.2018.8442104

Mayrhofer, M., Goos, J., Witters, M., and Egyed, A.: Explore Design Spaces using a generic framework." REM 2018, 19th International Conference on Research and Education in Mechatronics, pp. 24-29. IEEE. 2018. https://doi.org/10.1109/REM.2018.8421786

Murauer, M., Haslgrübler, M., and Ferscha, A.: Natural Pursuits for Eye Tracker Calibration. iWOAR 2018, 5th international Workshop on Sensor-based Activity Recognition and Interaction, Article No. 3, pp. 1-10. ACM. 2018. https://doi.org/10.1145/3266157.3266207

Nwabuona, S., Schuss, M., Mayer, S., Diwold, K., Krammer, L., and Einfalt, A.: Time-synchronized Data Collection in Smart Grids through IPv6 over BLE. IoT 2018, 8th International Conference on the Internet of Things, Article No. 25, pp. 1-4. ACM. 2018. https://doi.org/10.1145/3277593.3277632

Shafei, A., Hodges, J., and Mayer, S.: Ensuring Workplace Safety in Goal-based Industrial Manufacturing Systems. SEMANTiCS 2018, 14th International Conference on Semantic Systems, pp. 90-101. ELSEVIER. 2018. https://doi.org/10.1016/j.procs.2018.09.009

Thalmann, S., Mangler, J., Schreck, T., Huemer, C., Streit, M., Pauker, F., Weichhart, G., Schulte, S., Kittl, C., Pollak, C., Vukovic, M., Kappel, G., Gashi, M., Rinderle-Ma, S., Suschnigg, J., Jekic, N., and Lindstaedt, S.: Data Analytics for Industrial Process Improvement - A Vision Paper. CBI 2018, 20th Conference on Business Informatics, Vol. 2, pp. 92-96. IEEE. 2018. https://doi.org/10.1109/CBI.2018.10051

Thomay, C., Gollan, B., Haslgrübler, M., Ferscha, A., and Heftberger, J.: Modeling Worker State for Optimal Training of Novices in Complex Industrial Processes. ICETA 2018, 16th International Conference on Emerging eLearning Technologies and Applications, pp. 577-582. IEEE. 2018. https://doi.org/10.1109/ICETA.2018.8572151

Weichhart, G.: Representing Processes of Human-Robot Collaboration. S-BPM-ONE 2018, S-BPM-ONE Workshop Proceedings. CEUR-WS Vol. 2074. 2018. http://ceur-ws.org/Vol-2074/article_2.pdf

Weichhart, G., Akerman, M., Akkaladevi, S.C., Plasch, M. Fast-Berglund, A., and Pichler, A.: Models for interoperable human robot collaboration. IFAC-PapersOnLine Volume 51, Issue 11, pp. 36-41. ELSEVIER. 2018. https://doi.org/10.1016/j.ifacol.2018.08.231

Weichhart, G., Pichler, A., and Wögerer, C.: Workflow representations for human and artificial agent collaborations. ACHI 2018, 11th International Conference on Advances in Computer-Human Interactions. pp. 132-136, IARIA, 2018.

Weichhart, G., Fast-Berglund,A., Romero, D., and Pichler, A.: An Agent- and Role-based Planning Approach for Flexible Automation of Advanced Production Systems. IS 2018, IEEE 2018 International Conference on Intelligent Systems, pp. 391-399. IEEE. 2018. https://doi.org/10.1109/IS.2018.8710546

Zörrer, H., Weichhart, G., Plasch, M., and Vorderwinkler, M.: Chatting Roles: A Pragmatic Service Resolution Infrastructure for Service Choreography based on Publish/Subscribe. IFAC 2018, IFAC-PapersOnLine 51.11. ELSEVIER. 2018. https://doi.org/10.1016/j.ifacol.2018.08.335

Talks & Presentations

Ferscha, A.: Pro²Future. FFG Forum Produktion. Graz, Austria. 2018.

Ferscha, A.: Enterprise Interoperability. ICIST 2018, Keynote 8th International Conference on Information Society and Technology 2018. Kopaonik, Serbia. 2018.

Ferscha, A.: Pro²Future: Produkte und Produktionssysteme der Zukunft werden denken! JKU Transfertag. Linz, Austria. 2018.

Ferscha, A.: Spotlight 5 - IoT, the thinking things. ECSEL-Austria Conference. Linz, Austria. 2018.

Ferscha, A.: The Future of Products and Production Systems is Cognitive. Pro²Future in Progress. Linz, Austria. 2018.

Ferscha, A.: Shaping the cognitive productions systems of the future. INDustrial TECHnologies. Vienna, Austria. 2018.

Ferscha, A. and Pollak, C.: Pro²Future und CDP: Common Research Program. CDP Opening Event. Vienna, Austria. 2018.

Haslgrübler, M.: Cognitive Worker Assistance. ÖWGP Dissertationskolloquium. Vienna, Austria. 2018.

Theuretzbacher-Fritz, H., Pollak, C., and Weichhart, G.: Research for Industry 4.0 and beyond. Hannover Messe. Hannover, Germany. 2018.

Weichhart, G.: Future of Manufacturing and Logistics Systems. INCOM 2018, 16th IFAC Symposium on Information Control Problems in Manufacturing. Bergamo, Italy. 2018.

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